Deniz Turkcu

BATTLING WITH THE TENSIONS IN SUSTAINABLE PACKAGING

ACTA UNIVERSITATIS LAPPEENRANTAENSIS 1248

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Abstract

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This dissertation investigates the systemic tensions that arise during the transition from conventional plastics to sustainable packaging systems, focusing on biobased plastics and reusable packaging. While these eco-innovations are promoted as solutions to reduce environmental burdens, they often generate tensions leading to unintended consequences due to competing sustainability goals. The study is motivated by the need to understand and mitigate such tensions in order to support more effective sustainability transitions.

The dissertation builds on sustainability transitions, eco-innovation, and the dark side of sustainability literature to provide a systems-level perspective. Methodologically, it employs a mixed approach, combining a literature review with qualitative, exploratory research. Semi-structured expert interviews with diverse stakeholders such as businesses, NGOs, municipalities, and waste management organizations form the core empirical material. This multi-actor approach offers insights into how tensions emerge across different levels of the system.

The findings reveal that systemic tensions manifest at organizational, systemic, and policy levels, leading to tensions such as increased costs, inefficient resource use, consumer confusion, or infrastructural misalignments. At the same time, the research demonstrates that these tensions can be mitigated through a combination of firm-level strategies (e.g., process optimization, closed-loop models), systemic innovations (e.g., collaboration, standardization, localization), and policy interventions (e.g., supportive infrastructure, incentives, and regulations). Recognizing tensions as defining features of sustainability transitions, rather than as mere obstacles, provides a more realistic and actionable understanding of how eco-innovations evolve.

The dissertation contributes theoretically by integrating sustainability transitions with critical perspectives to foreground the “dark side” of eco-innovation. Practically, it provides actionable insights for managers and policymakers to anticipate and navigate tensions, thus avoiding lock-ins and supporting more resilient packaging transitions.

Keywords: sustainable packaging, eco-innovation, sustainability transitions, tensions, unintended consequences, biobased plastics, reusable packaging

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To the woman I became through this journey, shaped by courage, curiosity, persistence, resilience, solitude, change, hard work, uncertainty, and hope.
This is for you.
To my uncle, Erdinç.
May your name be remembered.

Contents

List of publications

This dissertation is based on the following papers. The rights have been granted by publishers to include the papers in dissertation.

I. Turkcu, D., Tura, N. and Ojanen, V. (2022). A Conceptual Framework of the Sustainability Challenges Experienced during the Life Cycle of Biobased Packaging Products. *Sustainability*, 14(17), 10465. https://doi.org/10.3390/su141710465

II. Turkcu, D. and Tura, N. (2023). The Dark Side of Sustainable Packaging: Battling with Sustainability Tensions. *Sustainable Production and Consumption*, 40, pp. 412-421. https://doi.org/10.1016/j.spc.2023.07.007

III. Turkcu, D. and Tura, N. The Role of End-of-Life Lock-Ins in the Diffusion of Eco-Innovations. Submitted 2025.

IV. Turkcu, D. and Levänen, J. Addressing tensions in a policy-led transition from single-use to reusable packaging in the takeout food sector in Germany. Submitted 2025.

Author's contribution

Deniz Turkcu is the principal author and investigator in papers I–IV.

In all the papers, the author made a substantial contribution to the conceptualization, the data collection and analysis, and the writing of the manuscript.

Nomenclature

Abbreviations

BPP	Biobased plastic packaging
CSR	Corporate social responsibility
EOL	End-of-life
LCA	Life cycle assessment
MLP	Multilevel perspective
ST	Sustainability transitions
EU	European Union
PPWR	Packaging and Packaging Waste Regulation

Declarations

Turnitin

The originality of this dissertation has been reviewed with the Turnitin similarity checking service.

Commercial software

This dissertation was prepared with the help of the following commercial software:

NVivo 12 – a qualitative data analysis software that is used for data coding, classification and analysis. NVivo licensed software is provided by LUT University for researchers. Deniz Turkcu utilized NVivo 12 for qualitative data coding and analysis in Publications II, III and IV.

Microsoft Teams – a collaboration and communication platform that is used for chat, file sharing, recordings, and transcription. Microsoft Teams licensed software is provided by LUT University for researchers. Deniz Turkcu utilized Microsoft Teams for conducting interviews, recording and transcription of the recordings in Publications II, III and IV.

AI use

During the preparation of this doctoral dissertation, Deniz Turkcu, the author of the dissertation, used Chat GPT Open AI in order to develop the presentation and grammar of textual information in the summary of the dissertation. After using Chat GPT Open AI, the author reviewed and edited the content and takes full responsibility for the content of the doctoral dissertation.

1 Introduction

The demand for conventional plastic packaging has grown substantially in recent years, driven by conditions such as rising urban mobility, shifting demographic patterns, and the surge in takeaway and delivery services throughout and following the COVID-19 pandemic (Simoens et al., 2022). As a result, the environmental burden of conventional packaging has also intensified, attracting increasing scrutiny due to its significant sustainability challenges. These challenges include contributions to marine plastic pollution, broader environmental degradation, depletion of natural resources, and escalating municipal costs related to waste management (Dorn and Stöckli, 2018; Gerassimidou et al., 2021; Maye et al., 2019). This has led to increasing pressure from public and political institutions, such as through the European Union's (EU) new Packaging and Packaging Waste Regulation (PPWR) (European Parliament and Council, 2024), to adopt more sustainable packaging options. In response, various eco-innovations have emerged in the market as sustainable packaging options intended to tackle the complex challenges posed by conventional plastics and fostering more sustainable consumption and production systems. These include reusable packaging systems designed to extend product life cycles (Wang et al., 2023), bio-based plastics made of renewable sources to reduce fossil resource dependency (Gerassimidou et al., 2021), and packaging made from recycled materials (Miller et al., 2021).

Eco-innovations refer to the creation and implementation of novel products, processes, services, or business models that reduce environmental impacts such as pollution, resource use through their entire life cycles compared to the relevant alternatives, and contribute to sustainable development (Carrillo-Hermosilla et al., 2010; Kiefer et al., 2017; Rennings, 2000). In the literature, eco-innovation, green innovation, sustainable innovation, and environmental innovation terms are often used interchangeably (Díaz-García et al., 2015; Hizarci-Payne et al., 2021; Hojnik and Ruzzier, 2016; Karakaya et al., 2014; Schiederig et al., 2012). However, subtle distinctions exist: eco-innovation, green innovation, and environmental innovation primarily emphasize environmental benefits (Paipa-Sanabria et al., 2025), whereas sustainable innovation adopts a more holistic perspective that includes environmental, social, and economic dimensions (Hermann and Wigger, 2017). Since sustainable packaging is mainly designed to deliver environmental and economic benefits, the term sustainable innovation is not used in this context. Among the terms that focus on environmental and economic benefits, eco-innovation is selected to conceptualize sustainable packaging products, as it is widely used in academic literature for sustainable packaging (e.g., Bhatti et al., 2023; Duan et al., 2024; Sumrin et al., 2021) and aligns with the definition of innovations that reduce environmental impacts throughout their life cycle. In this regard, sustainable packaging qualifies as eco-innovation because it introduces new materials, designs, systems, and business models that improve resource efficiency, reduce waste generation, and minimize greenhouse gas emissions compared to conventional packaging.

Even though sustainable packaging options are seen as well-intended innovations to shift from conventional plastic to more sustainable packaging, they also pose unintended

consequences due to tensions experienced in their production and consumption. Unintended consequences are defined as negative outcomes that were not anticipated and lie beyond the original goals of deliberate actions (e.g., Merton, 1936; Leslie, 2019). In the case of sustainable packaging solutions, these unintended consequences include increased use of resources (such as energy, water, chemicals) in production, increased waste due to challenges in the end of life (EOL) of product life cycles and reduced shelf life of food, increased economic costs, health and safety concerns, and increased confusion among consumers. Tensions refer to the inherent conflicts that emerge when multiple sustainability goals, such as environmental protection, economic viability, and social equity are pursued simultaneously (Bansal and Song, 2017; Hahn et al., 2015). These tensions arise because the goals within sustainability can be contradictory or impose competing demands on resources, stakeholders, or organizational priorities (Kogg and Mont, 2012). For instance, efforts to reduce plastic waste may lead to higher resource consumption in the production of biobased materials; biodegradable packaging may shorten food shelf life, creating a tension between environmental sustainability and food security; and eco-labels intended to guide consumers may instead generate confusion, highlighting the tension between promoting sustainable behavior and ensuring social clarity and trust.

Tensions leading to unintended consequences should be understood and managed in order to achieve more integrated and effective sustainable outcomes (Smith and Lewis, 2011). While doing so, taking a holistic perspective is essential as it captures interconnected interdependencies in the system where actions in one area can affect other parts of the system (Sterman, 2000; Voulvoulis et al., 2022). For instance, a packaging innovation intended to reduce plastic use might inadvertently increase production costs, create consumer confusion about proper disposal, or shorten the shelf life of food products, illustrating how design choices in one part of the system can generate unintended consequences in other areas. Moreover, taking a holistic perspective can help prevent narrow solutions and ensure overall sustainability is achieved considering economic, social, and environmental dimensions; rather than only one dimension (Geels, 2011).

This dissertation identifies the systemic tensions leading to unintended consequences in sustainable packaging through sustainability transitions literature. Moreover, it identifies mitigation strategies to refer to these tensions. The sustainability transitions (ST) literature offers holistic perspectives on how systemic shifts toward more sustainable modes of production and consumption unfold within complex socio-technical systems (Geels, 2004; Köhler et al., 2019). In the context of transitioning from conventional plastic packaging to sustainable packaging, this literature underscores the need to study these products holistically, not merely as economic mechanisms but as integrated components of socio-technical systems. The sustainability transitions literature offers a comprehensive lens that enables stakeholders such as researchers, practitioners, and policymakers to understand the complex interdependencies and feedback loops influencing the feasibility, scalability, and long-term success of sustainable packaging options (Geels, 2004; Markard et al., 2012).

In this dissertation, the biobased plastic and reusable plastic packaging industries are studied as commercially and politically visible while developing sustainable packaging options that can provide rich insights in sustainability transition dynamics. While biobased plastic packaging presents an example of material innovation by focusing on what the product is made of as a sustainable packaging example; reusable packaging is chosen to give an example of a system innovation; innovating on how the packaging is used in the value chain. Biobased plastic packaging is chosen as an interesting sector to analyze because it sits at the intersection of sustainability, economics, technology, and policy, and is an eco-innovation sector that is still in its infancy. Biobased plastic packaging products are made of plant-based materials such as sugarcane and corn, which can be biodegradable or non-biodegradable (Spirerling et al., 2018). Their sustainability effects compared to conventional plastics are questioned due to performance issues, problematic end of life, feedstock problems, social concerns such as the potential risk to human health intensified by labeling, policy issues, consumer awareness, and behavioral issues (Gerassimidou et al., 2021).

Reusable packaging options are seen as an effective approach, as they can create significant decreases in material use, and in terms of environmental effects they can reduce CO_2 emissions by 60–80% compared to single-use alternatives (Coelho et al., 2020). Although sustainability transitions away from single-use packaging are increasingly emphasized in academic research and public policy, single-use packaging continues to dominate the market (Cimpan et al., 2023). Meanwhile, reusable packaging remains more of an ideal or optional solution rather than a mainstream practice, often perceived as a "nice-to-have" rather than a necessity due to systemic problems (Simoens et al., 2022). Hence, reusable packaging is chosen as one of the sectors to be investigated within sustainable packaging. These examples were chosen over other options such as recyclable packaging because they capture different yet complementary transition pathways; material substitution and system redesign, thereby enabling an exploration of a broader spectrum of socio-technical changes and the interactions between technological, behavioral, and policy factors.

1.1 Research Gaps

Research Gap 1 - *Gap in critical studies examining the unintended consequences and tensions of eco-innovations*

Eco-innovation is considered to be a relatively young concept receiving great attraction in the scientific community and among policymakers, with developing clarifications on the concept and discussions from different perspectives and levels of analysis in academia (Gente and Pattanora, 2019). Eco-innovations are studied in the literature focusing on how eco-innovations can be useful to companies by analyzing how they contribute to a firm's economic performance (Hojnik et al, 2018; López Pérez et al., 2024), its circular economy transition (Scarpellini et al.; 2020), and the motivations, barriers and capabilities

of companies for employing eco-innovation solutions (del Río et al., 2016; Hojnik and Ruzzier, 2016; Kiefer et al., 2019). Some studies concentrate on the diffusion of eco-innovations through consumer adoption (e.g., Jansson, 2011), while others examine the role of policy-driven initiatives (e.g., Fernández et al., 2021). There are also some studies that take a more holistic perspective on how eco-innovations can contribute to broader sustainable development (Smol et al., 2017), exploring the synergies of eco-innovation within the general sustainability debate. There is also a growing body of literature that attempts to understand the definition of eco-innovations and the underlying characteristics without taking a critical perspective on the challenges or whether eco-innovations are inherently sustainable (e.g., Carrillo-Hermosilla, 2010; Kiefer et al, 2017; Xavier at al., 2017). The scientific community recognizes that the adoption of eco-innovation facilitates systemic advancements in processes, technologies, and services, yielding benefits for both sustainability and organizational outcomes (Gente and Pattanora, 2019). However, few studies critically examine whether eco-innovations are truly sustainable, including the unintended consequences and tensions they may generate (e.g., Nawaz and Bashir, 2022), often referred to as the "dark side of sustainability," which highlights the negative impacts and trade-offs that sustainability initiatives can inadvertently cause.

Research Gap 2 – *Gap in critical examination of the tensions in sustainability transition studies*

There has been an increasing body of literature that analyzes the sustainability assumptions in transition studies conducted over the past 15 years. Sustainability transitions literature was started and continues to be driven by the Sustainability Transitions Network, with an initial mission statement and research agenda published in 2010 (STRN, 2010). The idea of this body of literature is based on environmental problems caused by unsustainable consumption and production patterns not being able to be resolved through incremental changes but requiring radical transformations in socio-technical systems (Grin et al., 2010; Köhler et al., 2019). It underlines the transdisciplinary nature of the research seeing the long-term broader picture (Köhler et al., 2019). Some recent literature acknowledges that sustainability can be a fuzzy term that is highly context-dependent, and a solution to a certain problem can create unintended consequences in other sustainability goals within the broader sustainability research (e.g., Carter et al., 2020; Fuso Nerini et al., 2018; Moallemi et al., 2022; Schleper, 2020), but this research within specific ST literature is limited (e.g., Gebreselassie et al., 2025; Kainiemi et al., 2025; Markard et al., 2023; Lai and Karakaya, 2024). Identifying the unintended consequences, trade-offs, and tensions leading to them is seen as a gap in the literature (Köhler et al., 2019; Susur and Karakaya, 2021) and hence was even selected as the main theme of the annual STRN conference of 2025: "Tensions and trade-offs in structural changes for sustainability transitions" (Sustainability Transitions Research Network (STRN), 2025).

Research Gap 3 – *Gap in analyzing policy outcomes that lead to tensions in sustainability transition studies*

Transition studies widely acknowledge the importance of policy for providing directionality with regulations, standards, taxes, subsidies, and innovation policies (Köhler et al., 2019). There are even frameworks such as transition management that aims to analyze how policymakers can shape transitions (Loorbach, 2009). Most research about policy within sustainability transitions literature focuses on the design processes of the policy; contextualized as policy processes in terms of actor coalitions creation, agenda setting, power relationships, agency affect the sustainability transitions (e.g., Kern, 2011; Hess, 2014; Normann, 2017, 2015). Some studies focus on the substantive content of policies and examine how specific goals and design features influence the direction, pace, and nature of sustainability transitions. There are also studies that examine the governance of policies, with a particular focus on the use of regulatory, economic, and informational policy instruments (e.g., Kivimaa and Kern, 2016; Rogge and Reichardt, 2016), policy coherence and fragmentation, and the alignment of measures across sectors and levels of governance. Even though many studies focus on how policies emerge and are governed, there is a clear gap in policy outcomes: real-world effects, observable results, or changes from policies into systems is underlined in the sustainability transitions literature (Köhler et al., 2019; Markard et al., 2016). Going one step further, research rarely considers how the consequences of policies might materialize as tensions between actors, practices, or system levels. When a new policy is implemented, it often encounters numerous challenges stemming from established norms, rules, shared beliefs, and practices among various stakeholders, including government professionals (Bakkeli, 2022), citizens or consumers (Zhang et al., 2024), and actors in the private sector, government, and production industry (Amaruzaman et al., 2023). Hence, tensions are inevitable in the context.

Research Gap 4 – *Gap in empirical research on sustainable packaging taking a holistic and interdisciplinary view*

Existing research on sustainable packaging often typically emphasizes particular themes such as material properties (e.g., Masilamani et al., 2017) environmental impacts (e.g., De Léi et al., 2016), or consumer perceptions (e.g., Magnier and Schoormans, 2015), but there is a lack of comprehensive analyses that integrates multiple dimensions across the entire packaging life cycle. Comprehensive analyses that integrate multiple dimensions across the entire packaging life cycle are essential, because sustainable packaging is a complex, systemic challenge that cannot be fully understood through isolated or purely technical assessments. A holistic approach captures the interconnections between design, production, consumption, and disposal, while also accounting for social, cultural, institutional, and behavioral factors that influence packaging decisions and outcomes (Svanes et al., 2010). Such analyses provide deeper insights into stakeholder perspectives, trade-offs, and real-world constraints, helping to identify practical barriers and opportunities for more effective, scalable, and context-sensitive solutions. This broader understanding is crucial for developing packaging strategies that are not only environmentally sound but also socially and economically viable across different settings.

Even though some studies try to create holistic methodologies for sustainable design (e.g., Svanes et al., 2010), holistic studies of their sustainability are limited. Moreover, the complexity of sustainable packaging requires interdisciplinary research that combines insights from design, material science, consumer behavior, and policy. However, current qualitative studies often remain siloed within specific disciplines, lacking a comprehensive approach that considers all relevant factors influencing sustainable packaging decisions. Within sustainability transitions literature, which is acknowledged to be holistic and interdisciplinary, most studies focus on electricity and transport with increasing literature on other topics such as food, water, heat and buildings, cities and waste management (Köhler et al., 2019), while studies focusing on sustainable packaging is limited.

1.2 Objective of the research and research questions

Understanding the complexities of transitioning to sustainable packaging requires examining not only the intended benefits but also the systemic tensions leading to unintended consequences. Even though some tensions can create positive impacts, such as the creative tension from improving innovation, most tensions result in negative outcomes (Tóth et al., 2018). To address the overarching research question on systemic tensions leading to unintended consequences in sustainable packaging transitions, this dissertation breaks down the inquiry into four interrelated sub-questions, providing a structured pathway from identifying foundational challenges to proposing strategies for mitigation. Sub-question 1 identifies the foundational sustainability challenges in sustainable packaging, which are the early sources of systemic tensions. Sub-question 2 builds on this by analyzing how these tensions manifest across the life cycle of eco-innovations, from production to use to end-of-life, revealing stage-specific pressures that contribute to broader systemic issues. Sub-question 3 adds the policy dimension, examining how regulatory interventions can trigger new tensions or exacerbate existing ones, showing that systemic tensions are shaped not only by technology and behavior but also by governance structures. Sub-question 4 moves from analysis to action, exploring strategies and solutions for mitigating the identified tensions, providing insights for businesses, policymakers, and other stakeholders.

Main question: ***What are the systemic tensions experienced during transitioning to sustainable packaging systems that are leading to unintended consequences and how can they be mitigated?***

The overarching research question in this dissertation is answered through four publications. An overview of the four publications described in the following paragraphs can be found in Table 1.

Sub-question 1: What are the common sustainability challenges of sustainable packaging?

This question supports understanding the systemic tensions asked in the main question, surfacing the foundational issues within sustainable packaging such as the sourcing materials, recyclability, supply chain disruptions, cost, and performance issues. Analyzing the existing, concrete, and tangible sustainability issues helps to identify early sources of tensions as these challenges often evolve into systemic tensions. Once these foundational challenges are understood, how these challenges interact at the system level, potentially conflicting with each other, creating pressures, and ultimately leading to unintended outcomes can be analyzed to answer the main question. Also, this question helps to map actors to be investigated that are facing systemic tensions. Mapping the actors is essential to analyze the systemic tensions and unintended consequences during the transition to sustainable packaging systems, as systemic tensions do not exist in a vacuum; they are experienced and shaped by people, organizations, and institutions. Publication 1 is prepared to answer this question using a literature review methodology.

Sub-question 2: What are the tensions experienced during the life cycle stages of sustainable packaging?

To gain a better understanding of the systemic tensions transitioning to sustainable packaging, analyzing the life cycle tensions is beneficial. Taking the specific perspective of beginning of life (resource extraction), middle of life (production and use) and end of life to analyze tensions helps to systematically identify and understand the different challenges that arise at each stage of the sustainable packaging life cycle, revealing how these stage-specific tensions interact and contribute to broader systemic issues and unintended consequences during the transition to sustainable packaging systems. Understanding the full life cycle tensions helps to explain the systemic tensions during the transition to sustainable packaging. This perspective helps to ensure all stages of the packaging life cycle are covered, and also identify which life cycle stages may need specific attention in order to resolve the systemic tensions. For example, in Publication II, even though the exact life cycle approach is not taken to categorize the analysis, the researchers kept life cycle thinking in mind, which helped to reveal that EOL phase tensions need specific attention. In Publication I, taking the life cycle approach to analyze sustainability challenges also brought attention to the fact that EOL-related challenges are complex and prominent; requiring extra detailed attention. As a result, Publication III is designed to specifically analyze EOL tensions, conceptualizing them as systemic lock-ins.

Sub-question 3: What kind of systemic tensions arise when a specific policy is introduced?

Policies are seen as important factors that initiate or accelerate transitions by setting rules, incentives, or restrictions; as a result, they should be seen as an important part of possible systemwide tensions. Policies can create unintended consequences or resistance in the system, such as shifting burdens to other actors, creating loopholes, or misaligning with existing infrastructure. Hence, with the belief that specific consideration should be given to the role of policies while studying the tensions in sustainability transitions, this sub-

question is introduced, and Publication IV mainly investigated this question in light of multi-level perspective (MLP) as the theoretical framework.

Sub-question 4: How can the tensions be mitigated through different actions and strategies?

Understanding the tensions leading to unintended consequences is important in order to provide solution strategies. This sub-question helps to support the main question by explaining what needs to be done after the tensions leading to unintended consequences are analyzed to reduce, avoid, or manage these tensions. This question helps to provide practical insights relevant for policymakers, businesses, designers, or NGOs, going beyond theoretical insights provided in this dissertation. It strengthens the relevance of this research by exploring beneath problem identification and critical understanding of the tensions with a constructive path forward. Publication II addresses this question by taking the paradox perspective and adapting elements from paradox theory, Publication III addresses it by asking what kinds of strategies the companies are utilizing to resolve the systemic tensions, and Publication IV provides insights into what different actors can do to resolve the systemic tensions within a policy-led transition.

Table 1: Overview of publications and their objectives and methodology

Publications	Publication I	Publication II	Publication III	Publication IV
Title	A Conceptual Framework of the Sustainability Challenges Experienced during the Life Cycle of Biobased Packaging Products	The Dark Side of Sustainable Packaging: Battling with Sustainability Tensions	The Role of End-of-Life Lock-ins in the Diffusion of Eco-Innovations	Addressing Tensions in a Policy-led Transition from Single-use to Reusable Packaging in the Takeout Food Sector in Germany
Objectives	Categorizing the economic, environmental, and social challenges of the biobased plastic packaging sector and gaining an understanding of the main literature themes and gaps	Identifying and characterizing the various economic, structural, psychological, and behavioral tensions arising in the production of sustainable packaging within an emerging biobased plastics industry, and exploring the management strategies companies adopt to address these	Investigating how end-of-life (EOL) management lock-ins hinder the diffusion of eco-innovations in the biodegradable biobased plastic packaging sector, and identifying strategies innovators can use to overcome these barriers and accelerate eco-innovation adoption.	Analyzing the economic, structural, psychological, and behavioral tensions arising among stakeholders during Germany's policy-led transition from single-use to reusable packaging and exploring strategies to manage these tensions to facilitate sustainability transitions.

		unintended sustainability consequences.		
Research questions in the publications	1-What are the main environmental, social, and economic challenges associated with biobased packaging products in their different life cycle stages? 2-What are the missing parts and emerging themes in the current literature on the sustainability of biobased packaging products?	1-What are the characteristics of the tensions of sustainable packaging production? 2-How can companies manage such tensions in an emerging and innovative industry?	1-What is the relationship between eco-innovation diffusion and EOL lock-ins? 2-How can innovators overcome challenges related to eco-innovation diffusion that contribute to EOL lock-ins?	1-What kinds of tensions arise when a new policy is introduced into the system of reusable packaging? 2-What kinds of strategies can actors utilize to cope with (overcome) these tensions?
Methodology	Literature review	Qualitative semi-structured interviews	Qualitative semi-structured interviews	Qualitative semi-structured interviews
Empirical context	BBPP	BBPP	BBPP	Reusable packaging
Research gaps addressed or main research questions answered	-Sub-research question 1 -Sub-research question 2	-Sub-research question 2 -Sub-research question 4	-Sub-research question 2 -Sub-research question 4	- Sub-research question 3 -Sub-research question 4

1.3 **Research Scope**

The research scope of this dissertation is defined by the bodies of literature it engages with and contributes to. The study is situated at the intersection of sustainability transitions, eco-innovation, and critical perspectives on sustainability. Within this framing, the dissertation focuses on tensions, unintended consequences, and lock-ins that emerge in the transition from single-use to more sustainable packaging systems, especially biobased plastics and reusable packaging.

The dissertation builds primarily on three interconnected strands of literature:

1. **Sustainability transitions literature**: The work draws on multi-level perspective (MLP), lock-in theory, and related concepts to analyze systemic change processes.

   As the guiding theoretical lens, this dissertation adopts a systems-level perspective. Publications II and III gather insights from organizations to identify systemic tensions, while Publication IV strengthens and complements this analysis by examining tensions created by policy interventions. This combination ensures that the system is covered comprehensively enough for systemic insights to be drawn. The inclusion of diverse stakeholders (businesses, NGOs, municipalities, academia, waste management, and service providers) captures multiple viewpoints within the system. Moreover, the study addresses different stages of the packaging life cycle, from production and use to end-of-life management, ensuring that tensions are not confined to a single phase. By coupling these empirical insights with a sustainability transitions framework, the dissertation demonstrates that systemic tensions are addressed both at organizational and governance levels, providing a sufficiently comprehensive coverage of the system to support the analysis.

2. **Eco-innovation literature**: This body of work provides a framework for understanding sustainable packaging as an eco-innovation. It contributes to discussions on how eco-innovations diffuse, how they interact with incumbent regimes, and what unintended effects they may generate. The dissertation narrows its engagement to systemic and organizational aspects of eco-innovation rather than technological optimization.

3. **Critical sustainability and paradox literature**: The study incorporates insights from the "dark side of sustainability" perspective and paradox theory. These streams allow the dissertation to conceptualize sustainability not as a linear improvement but as a contested process marked by competing objectives and contradictions.

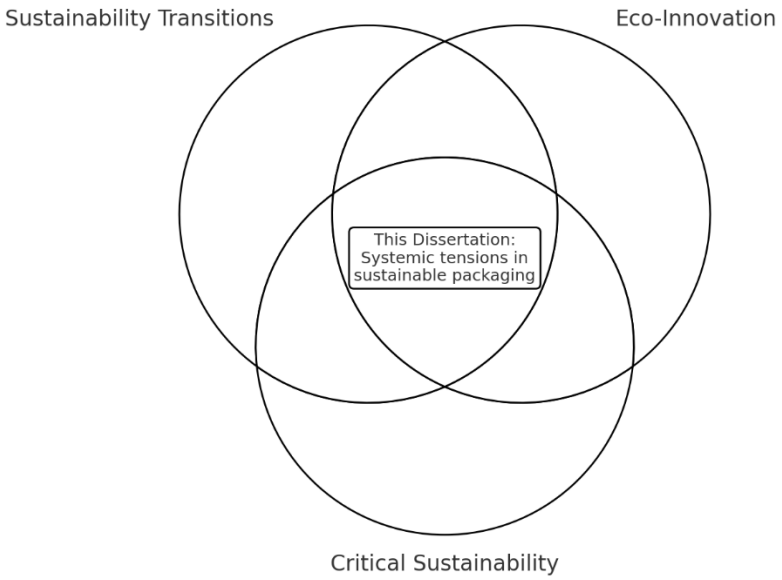

Figure 1: Research Scope

1.4 Outline of the Study

This dissertation is structured into five key chapters. The first chapter introduces the study by providing background information, identifying gaps in existing research, and outlining the primary objectives. Chapter 2 explores the theoretical framework, discussing relevant scholarly literature and key concepts that inform the research. Chapter 3 describes the research methodology, including methodological approaches, an explanation of research design choices and the data collection process. Chapter 4 presents the core results as detailed in four individual research articles. The final chapter, Chapter 5, addresses the research questions, discusses the study's theoretical, managerial, and policy related contributions. Moreover, it acknowledges its limitations and suggests avenues for future research.

2 Theoretical Background

2.1 Sustainability Transitions

Sustainability transitions (ST) research is introduced with the motivation to tackle grand social challenges such as climate change, loss of biodiversity, and the depletion of vital resources (Köhler et al., 2019). These challenges are caused by unsustainable patterns of consumption and production related to the dimensions such as the relationship between market, government, and society, and its guiding values as expressed through lifestyle patterns (Grin et al., 2010). ST literature recognizes that addressing such systemic problems cannot rely solely on incremental improvements or technological fixes; they necessitate profound transformations toward entirely new socio-technical configurations. This body of work seeks to conceptualize and explain how such changes unfold within the processes that sustain societal functions (Markard et al., 2012).

Sustainability transitions is a meso-level body of literature (Geels, 2004) that differs from many established research streams in the sustainability debate like micro-level theories focusing on individual choices, attitudes, and motivations, or macro-level theories that focus on changes in political economy like capitalism (Köhler et al., 2019). It is established in order to create a broader and longer-term view, acknowledging the systemic dimension compared to other sustainability approaches like industrial ecology, eco-innovation, or environmental economics that often emphasize narrower analytical foci (Markard et al., 2012; Loorbach et al., 2017).

Sustainability transitions research has several characteristics that differentiate it from other sustainability debates in the literature, mostly focusing on the transdisciplinary nature (Köhler et al., 2019). Sustainability transitions are characterized by multi-dimensionality and co-evolution. Socio-technical systems are composed of interrelated elements, including technologies, markets, user practices, cultural meanings, infrastructures, policies, industry structures, and supply and distribution networks (Geels, 2004; Markard et al., 2012). Transitions within such systems are therefore co-evolutionary processes involving simultaneous changes across multiple dimensions. These processes unfold over long periods and are marked by complex, interdependent dynamics rather than linear or predictable trajectories (Geels, 2011). They are also multi-actor processes. Transitions are driven by a wide range of actors spanning academia, politics, industry, civil society, and households, each with distinct resources, capabilities, beliefs, strategies, and interests (Smith et al., 2005; Köhler et al., 2019). This diversity makes transitions highly intricate processes that cannot be sufficiently explained through a single theoretical lens or disciplinary approach, highlighting the importance of interdisciplinary perspectives (Markard et al., 2012).

A central challenge in ST is understanding the interplay between stability and change**.** Socio-technical systems are stabilized by entrenched institutional structures and consumption routines that reinforce path-dependent trajectories, making systemic change

particularly difficult (Unruh, 2000; Geels, 2004). Nevertheless, transitions research focuses on how niches, innovations, and social movements can disrupt such stability and generate alternative pathways toward sustainability (Smith et al., 2010). Transitions also represent long-term processes. Radical environmental innovations typically begin in small, experimental niches and often require decades before achieving mainstream adoption (Geels and Schot, 2007). This slow progression reflects the systemic, cumulative nature of sustainability transitions and the structural challenges of scaling up environmentally friendly practices and technologies (Markard, 2018).

Open-endedness and uncertainty further characterize transitions. Innovation processes are non-linear and unpredictable, shaped not only by technological developments but also by shifting political contexts and socio-cultural dynamics (Raven et al., 2010; Smith and Stirling, 2010). As a result, it is often impossible to anticipate in advance which innovations, policies, or transition pathways will ultimately prevail. Moreover, ST involve values, contestation, and disagreement**.** The concept of sustainability is contested, with actors and social groups holding divergent views on which innovations and pathways are most desirable (Stirling, 2008). Because transitions often challenge the strategic interests of incumbent industries such as oil, automotive, utilities, and agro-food sectors, these powerful actors frequently resist change in order to maintain their dominance (Geels, 2014; Hess, 2014). Finally, transitions are normatively oriented. Since sustainability represents a public good, neither consumers nor firms have sufficient incentives to drive systemic change on their own. Public policy thus plays a central role in steering transitions by setting goals and deploying instruments such as regulations, standards, taxes, subsidies, and innovation incentives (Kemp et al., 2007; Loorbach, 2009). Establishing clear normative directionality is therefore crucial for aligning innovation efforts and societal change processes with sustainability objectives (Markard et al., 2012).

Within ST research, there are four main conceptual frameworks (Markard et al., 2012). Strategic niche management (SNM) examines how the radical technologies can be nurtured, shielded, and advanced within “niches” which are small, protected spaces to create regime shifts (Kemp et al., 1998). Transition management is a practical, tool-oriented framework that aims to steer societal transitions toward sustainability (Loorbach, 2009). Technological innovation systems theory explains how the development, diffusion, and use of a specific technology depend on the interactions between actors, networks, and institutions that together form a system enabling or constraining innovation (Bergek et al., 2008; Jacobsson and Johnson, 2000; Hekkert et al., 2007). It focuses on how effectively an innovation system supports the diffusion of new technologies through key functions such as knowledge development, influence over the direction of research, entrepreneurial experimentation, market formation, legitimation, resource mobilization, and development of positive externalities (Hekkert et al., 2007). Lastly, multi-level perspective (MLP) is a predominant framework for understanding how sustainability transitions unfold through interactions across different levels of socio-technical change (Geels, 2002; Geels, 2011).

2.1.1 Multi-Level Perspective (MLP)

MLP is one of the main analytical frameworks within ST research that is rooted in evolutionary economics, the sociology of innovation, and institutional theory (Köhler et al., 2019). The framework is focused on sustainability transitions in the "socio-technical" systems, such as the energy, sanitation, transport, housing and agro-food (Geels, 2011). Socio-technical systems transitions conceptualization refers to the co-evolving technological, social, institutional, and economic changes in the systems (Patterson et al., 2017) where technology and innovations are taken as an entry point of analysis (Geels, 2011) to fulfil societal functions (Geels, 2004).

MLP suggests that transitions arise from dynamic interactions occurring across three analytical levels: (1) niches, which are protected spaces where radical innovations develop; (2) socio-technical regimes, representing the institutionalized structures of existing systems that promote path dependency and gradual change, and (3) socio-technical landscapes, encompassing both gradual developments such as shifts in demographics, cultural norms, public concerns, global politics, and broad economic trends and sudden disruptions like wars, financial collapses, accidents, or spikes in oil prices (Geels 2002;2004). Innovations often originate within niches, where new actors such as pioneers and entrepreneurs cultivate alternative solutions (Rip and Kemp, 1998). These niche innovations can expand more broadly when pressures from landscape-level changes create instability within the regime, resulting in cracks, tensions, and opportunities for change. The ongoing interaction between niches and regimes spans various dimensions including markets, regulations, cultural meanings, and technologies, and involves interpretive actors who engage in processes of conflict, negotiation, exploration, learning, and coalition-building as they steer the transition. Central to this MLP is the systemic nature of transitions and the ongoing tension between stability and transformation, reflected in the interplay of varying degrees of structure across the niche, regime, and landscape levels (Köhler et al., 2019).

MLP suggests that socio-technical transitions occur in four main phases (Figure 2). The experimentation phase refers to the trial-and-error phase of pioneers where they learn about the performance, adoption, and feasibility of the innovations. In the second phase, innovations start to be accepted by the market after increased learning processes, experiences backed up by standardization, and by integration into customers' routines. In the third phase, innovations diffuse into the dominant market thanks to the improvements in price/performance, the development of complementary technologies, and strategic support from influential stakeholders. In this phase, economic and strategic competition between the niche innovations and incumbent technologies increases, and political conflicts and power and cultural struggles about problem framing may emerge. If the niche innovations can overcome these struggles, new innovations replace the old ones in the institutionalization and anchoring phase (Geels, 2019).

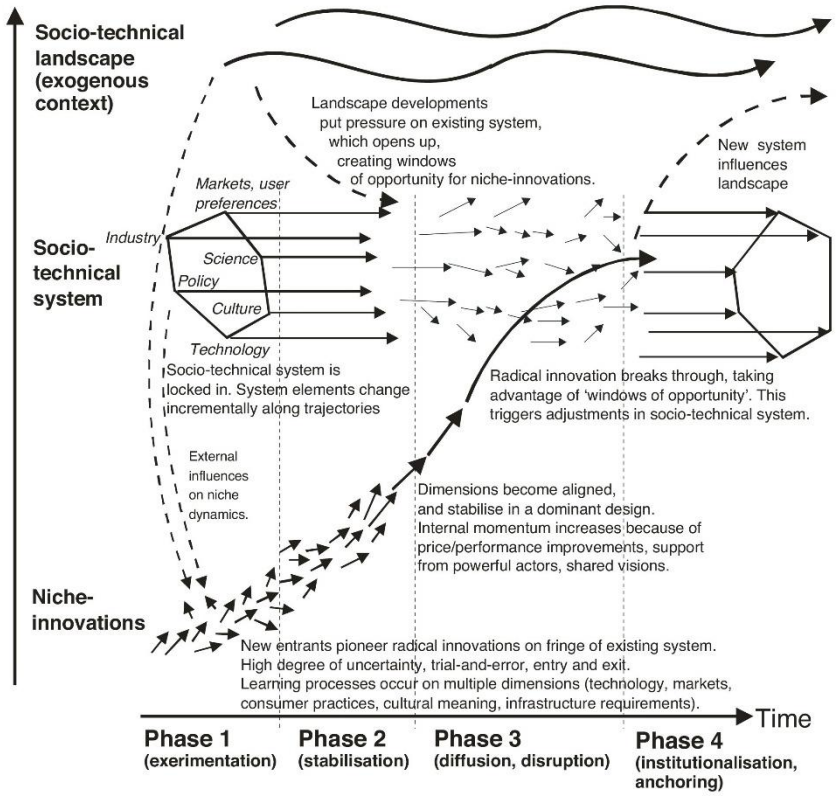

Figure 2: Multi-level perspective on socio-technical transitions (Geels, 2019)

2.1.2 **Lock-ins**

In the sustainability transitions literature, the lock-in concept is used to explain how existing sociotechnical systems resist change and perpetuates the system's current state or trajectory due to self-reinforcing technological, institutional, and behavioral mechanisms, highlighting why shifting to more sustainable alternatives can be slow and difficult (Cecere et al., 2014). As adoption of a technology grows, the accumulated benefits such as cost reductions, user familiarity, and network effects tend to strengthen the position of existing incumbent technologies, making it harder for new alternatives to compete (Arthur, 1994).

Lock-ins are considered to be fluid, emerging, persisting, and sometimes dissolving or evolving in response to new knowledge, innovations, regulatory shifts, or changes in market dynamics (Eitan and Hekkert, 2023). It is emphasized that lock-ins do not occur in isolation but are deeply embedded within complex systems where technological, economic, social, cultural, and political dimensions interact and mutually shape the persistence or transformation of these lock-ins (Sydow et al., 2009). Lock-ins contribute to the "escalation of commitment"; the tendency to persist with uncertain or risky efforts, even when success is unlikely, causing it to persist on a specific course even when better

alternatives exist (Eitan and Hekkert, 2023). As a result, lock-ins pose significant barriers to sustainability transitions, as these require flexibility and structural change to enable the adoption of new technologies, institutions, and practices for long-term environmental and societal transformation (Ampe et al., 2020).

In the literature, lock-ins are analyzed through technological (or material) (Arthur, 1994; Foxon, 2014), institutional (Arthur, 1994), behavioral (Seto et al., 2016), and discursive systems (Simoens et al., 2022). These broad categories include sub-categories that enhance the understanding of specific lock-ins. This comprehensive approach offers a nuanced and holistic framework for grasping the intricate dynamics that sustain lock-ins in various contexts.

Technological lock-ins are subcategorized as economies of scale, technological learning effect, network economies, and return on investment, and are linked to technological development. Economies of scale is a lock-in associated with sunken costs from a dominant existing technology resulting in lower unit costs for products using earlier technology, reinforcing market share (Arthur, 1994). Technological learning effects, another technological lock-in, refers to the issue when an innovation exists for a long time, and the technology improves through skill and knowledge accumulation. As a result, earlier technologies are usually more technologically mature and have high operational efficiency, as well as being cost-effective, and novel niche technology thus requires time to be able to compete with earlier technology (Arthur, 1994). Technological lock-ins are also linked to network economies, which can be explained by current infrastructure and systems being designed for the dominant technology, and niche approaches thus need to be compatible with existing infrastructure. This situation may limit the development of new technologies and prevent the adoption of innovative solutions (Arthur, 1994; David, 1985). A further technological lock-in is the need for return on investment, which explains the difficulty in changing the current system, especially in terms of infrastructure as that requires a high amount of investment costs (Seto et al., 2016).

Institutional lock-ins include collective action, adaptive expectations of institutions, institutional learning effects and power asymmetries, and refer to the lock-ins created by existing institutions such as regulatory bodies and various organizations and stakeholders in the current system. Collective action refers to the coalitions and arrangements in the system and the network of actors that underline the dependent situation of the individuals and organizations (Klitkou et al., 2015). Adaptive expectations of institutions explain the reduced uncertainty of the current institutions that reinforces the usage of dominant technology. Institutional learning effects refer to the improved coordination and match within the system of formal and informal institutions that underline existing technologies (Salmenperä et al., 2021). Power asymmetries refer to the power that the representatives of existing technology have in terms of creating the rules (Seto et al., 2016).

Behavioral lock-ins that are subcategorized as habituation, risk avoidance, and social structure, referring to the existing habits and culture that reinforce the use of dominant

technology (David, 1985). Habituation refers to the unconscious attachment that consumers and professionals have to current technologies and behavioral patterns, even though a better technology exists; they are consequently resistant to change. Habits are related to the routines and mechanisms that prevent individuals from putting effort into adopting the new routines that the new technology would require (Kotilainen et al., 2019). Risk avoidance is a pattern of behavior where individuals do not want to change their behavior and actions due to the risks, real or misperceived, that new habits and systems might bring. As a result, resistance to change prevents new practices from being adopted (Seto et al., 2016; Zauberman, 2003). Social structure refers to the existent societal norms and beliefs that new technology may need to disrupt and change (Seto et al., 2016).

Discursive lock-ins are subcategorized as unchallenged ideas, co-option, and incumbents' agency, which are caused by the dominant narrative in society and industry. Unchallenged ideas refer to unconscious dominant ideas and assumptions that reinforce the use of dominant technology and create resistance to change (Simoens et al., 2022). Co-optation refers to the narrative of the niche industry not being radical enough for it to replace the dominant narrative (ibid). Incumbents' agency is the ability of a dominant technology's actors to control and shape the dominant discourse (ibid).

2.2 The Dark Side of Sustainability

The "dark side" of sustainability literature refers to research and critiques that challenge the often overly positive, idealized, or "win–win" narrative around sustainability by highlighting the negative, unintended, or hidden consequences of sustainability initiatives, discourses, and practices. It focuses on how sustainability efforts can sometimes reinforce inequalities, mask harmful practices, or produce paradoxical outcomes. This body of literature has been increasing in recent years.

2.2.1 Tensions and Trade-Offs

Tensions are defined as negative consequences such as strain or conflict individuals or entities within a network experience due to diverging objectives, motivations, viewpoints, or interests (Hahn et al., 2015; Tschiedel et al., 2024). In the context of sustainability, tensions can arise at different levels and in varying contexts (Hahn et al., 2015; Sitaloppi et al., 2020). These tensions are caused by how stakeholders and systems interpret and prioritize intertwined social, economic, and environmental priorities (Hahn et al., 2015), the types of changes required to address them (Sitaloppi et al., 2020), and their anticipated timeline and geographical scale (Papachristos et al., 2013). In the sustainability context, most tensions happen as a result of the conflict between immediate economic decision-making and the broader, often delayed global externalities and extended effects of those choices (Hahn et al., 2015). These tensions are frequently interpreted differently by various participants in the system and may stem from flawed communication mechanisms

(such as mixed or ambiguous messaging, as well as lack of communication) and poorly structured planning processes (Tóth et al., 2018). Engaging a wider variety of actors at multiple decision-making levels (Baraldi et al., 2011; Seshadri, 2013), as well as extending connections across larger stakeholder networks and supply chain collaborators (Meqdadi et al., 2017; Öberg et al., 2012), also increase potential tensions.

In the CSR literature, these tensions are often classified into four categories: economic, structural, psychological, and behavioral.

Economic tensions may arise when product performance declines or costs rise, when investments or operational changes (like infrastructure overhauls) are necessary, or when prices become unpredictable (Tura et al., 2019). Such issues typically reflect a misalignment between stakeholders' perceived benefits and their capacity or willingness to extract value (Tóth et al., 2018). Structural tensions concern organizational governance and stakeholder relationships (Galati et al., 2021). They may appear when there are no clear standards or guidelines to direct operations, or when existing institutional rules conflict with newly introduced infrastructures (Turkcu and Tura, 2023).

Psychological tensions involve mental factors such as attitudes, cognitive models, or different perceptions of actors (Slawinski and Bansal, 2015). Examples include apprehension about marketplace risks (Peltola et al., 2016), uncertainties surrounding commercialization, or fears of policy changes and their possible negative implications (Haaja and Harikkala-Laihinen, 2025). Behavioral tensions are tied to habitual routines, actions, and communication practices (Tóth et al., 2018). They can manifest as increased demands on stakeholders for education, dialogue, decision-making, or changes in daily workflows (Turkcu and Tura, 2023).

A concept closely related to tensions is that of trade-offs, which occur when gains in one domain necessitate compromises in another (Byggeth and Hochschorner, 2006). Within approaches to product development and procurement, trade-offs emerge when decision-makers must weigh alternative solutions that emphasize different features or priorities. In the realm of corporate sustainability, the term "trade-off" denotes situations in which it is impossible to simultaneously fulfil economic, environmental, and social goals (Hahn et al., 2010, 2018). These scenarios entail concessions between at least two competing dimensions of sustainability. Sustainability-related trade-offs and tensions can occur at different levels and also emerge between those levels. For instance, Hahn et al. (2010) present a framework of corporate sustainability trade-offs that includes four levels: individual, organizational, industry, and societal. Ultimately, sustainable development is influenced by the perceptions, motivations, values, and choices of individual actors. Consequently, trade-offs at the individual level are closely tied to the decisions made by these actors, particularly within the context of corporate sustainability and the roles of individual decision-makers (e.g., Bansal, 2003; Burton and Goldsby, 2009; Hahn et al., 2010; Hemingway and Maclagan, 2004). At the *organizational level*, trade-offs in corporate sustainability arise when companies face tensions between varying sustainability objectives concerning their own role and impact as standalone entities

(Hahn et al., 2010). According to Hahn et al. (2010), trade-offs in sustainability at the *industry level* involve conflicts among various sustainability issues within industries as organizational fields. These conflicts encompass not only organizations but also other pertinent actors at the industry level, such as NGOs and regulators. Furthermore, at the *societal level* trade-offs refer to conflicts concerning the contribution of companies to a more sustainable society at large (ibid.). According to trade-off literature, conflicts between sustainability goals occur and cannot be achieved at the same time. When managing trade-offs, the tension between conflicting objectives is resolved by prioritizing one goal at the expense of another (Brix-Asala et al., 2018; Van der Byl and Slawinski, 2015). For instance, one might willingly accept a modest decline in financial returns in exchange for generating significant environmental improvements (Hahn et al., 2010).

2.2.2 **Paradox Theory**

While a trade-off approach is based on choosing between the competing demands of a firm to manage tensions, paradox theory adopts an alternative view of managing the tensions by analyzing how organizations can manage multiple, conflicting demands at the same time (Smith and Lewis, 2011). While prioritizing between competing tensions may boost performance in the short term, a paradox perspective contends that sustainability in the long term depends on ongoing initiatives to address managing diverse and conflicting requirements at the same time (Lewis, 2000). Paradoxes are defined as "contradictory yet interrelated elements that exist simultaneously and persist over time" (Smith and Lewis, 2011). Paradox theory proposes the identification and open addressing of the paradoxical tensions between these elements, as well the analysis of the responses that embrace tensions simultaneously (van der Byl and Slawinski, 2015). In the sustainability context, managers should recognize the interdependence of economic, environmental, and social challenges and, by recognizing and accepting sustainability tensions and their divergent elements, apply paradox thinking to balance financial performance with ethical commitments for social and environmental well-being, thereby contributing to sustainable development (Hahn et al., 2016, 2018).

Smith and Lewis (2011) identify four primary sources of paradoxes in organizational settings—performing, learning, belonging, and organizing—noting that tensions may arise both within each category and in the interactions between them.

Performing paradoxes are rooted in the multiplicity of goals imposed by both internal and external stakeholders (Smith and Lewis, 201). In relation to sustainable development, they relate to the challenge of addressing diverse and sometimes competing sustainability priorities (Hahn et al., 2018) between social, environmental, and economic outcomes that can be in competition with one another, both in the short and long term (Hahn et al., 2015; Slawinski and Bansal, 2015). Learning paradoxes arise in situations where systems must evolve, innovate, and renew themselves in response to changing conditions (Smith and Lewis, 2011). Long-term sustainability often requires simultaneously drawing on the existing system while dismantling parts of it to make space for new opportunities or adaptations to future demands. Such tensions tend to become most visible during periods

of transition or organizational change and are often framed as contrasts such as “old versus new,” “stability versus change,” or “present versus future” (Schad et al., 2016).

Belonging paradoxes are linked to differing identities, interests, values, and perspectives held by individuals or groups within a given context (Smith and Lewis, 2011) and they are common when stakeholders hold divergent views on social, economic, and environmental priorities (Hahn et al., 2018). Organizing paradoxes occur when organizations put in place competing processes or structures in pursuit of their objectives (Smith and Lewis, 2011), as there are challenges to deciding how best to achieve a specific purpose. They may present as contrasts such as “empowerment versus control,” “cooperation versus competition” (Manzhynski and Figge, 2020), or “integration versus separation” (Smith and Lewis, 2011; Sandberg, 2017).

In paradox theory, tensions management theories are divided into acceptance, spatial and temporal separation, and synthesis strategy. Acceptance strategy involves acknowledging and recognizing the existence of the tension and choosing to live with it rather than ignoring it (Schad et al., 2016). Both opposing aspects of the tension are considered viable at the same time, even though they are fundamentally contradictory (Smith et al., 2012). With the organization finding ways to coexist with the tensions, this approach can serve as a driver for transformation, and the tension can eventually bring about its resolution (Hahn et al., 2015; Graetz and Smith, 2009). Rather than merely acknowledging the incompatibility between opposing elements, organizations can reframe their perception of tensions to identify opportunities for the simultaneous realization of both conflicting aspects by situating their interrelated yet divergent components within a broader context (Xiao et al, 2019). After making tensions and paradoxes more manageable by considering the broader context, organizations can then apply resolution strategies, such as separation or synthesis. The separation strategy can take two forms: temporal and spatial. Spatial separation entails isolating diverse interests, expectations, and procedures, or viewpoints through organizational levels, between micro and macro contexts, or between different physical places (Poole and Van de Ven, 1989). Conversely, temporal separation addresses one side of the tension at a given time and the other at a later stage (Jarzabkowski et al., 2013). Finally, the synthesis strategy seeks to reframe the tension by incorporating new perspectives or elements that make it possible to integrate both opposing dimensions (Schad et al., 2016).

2.3 **Eco-innovation**

The body of literature on eco-innovation has expanded significantly in recent years, with studies approaching the topic from both business and policy perspectives (Hazarika and Zhang, 2019). It engages with diverse technological fields, ranging from construction and digital technologies to agriculture, recycling, water management, and bio-based materials, and often includes novel business models (Directorate-General for Research and Innovation, 2015). According to the Organisation for Economic Co-operation and

Development (OECD, 2009), eco-innovation differs from other forms of innovation in two fundamental ways. First, it contributes to a reduction in environmental impact, whether this effect is intentional or incidental. Second, its influence often extends beyond the immediate boundaries of the innovating organization, potentially engaging broader societal systems and encouraging shifts in socio-cultural norms and institutional structures (Gente and Pattanora, 2019).

Eco-innovation emerged from the idea of "appropriate technology" introduced by Ernst F. Schumacher in the 1960s, which promoted development with minimal environmental harm. While early economists from the neo-classical economics school like Garrett Hardin (Hardin, 1968) believed technology and markets could solve environmental issues, critics highlighted ecological limits and the need for deeper change (e.g., Solow, 1974). Hence, even though the concept of eco-innovation emerged within a theoretical framework grounded in a positivist belief in the potential of technology to address environmental challenges (Pansera, 2011), it was soon acknowledged that such innovations often generate both environmental and knowledge-related externalities (Rennings, 2000). Consequently, this has led to a growing call for policy support to drive eco-innovation as well as more consideration with social and institutional dimensions, as technology does not function in isolation but has an impact on the whole of society. To summarize, the understanding of eco-innovation has shifted from being viewed merely as a technical tool to being recognized as a socially embedded concept. This transition is also reflected in the theoretical landscape, which has moved away from the strict cost–benefit analyses of neo-classical economics toward more dynamic, evolutionary perspectives that explore the complex interplay of limited rationality and social context influencing eco-innovation (Hazarika and Zhang, 2019).

Eco-innovation is typically categorized as either radical or incremental. Incremental eco-innovations involve gradual enhancements to existing systems, such as component improvements or process optimizations. Conversely, radical eco-innovations entail substantial, often disruptive changes that do not align with current systems, leading to the creation of entirely new technologies or operational frameworks (Hazarika and Zhang, 2019). The literature highlights that eco-innovation frequently requires the participation of a broad spectrum of stakeholders from both the public and private sectors and institutions (Henriques and Sadorsky, 2007), and is defined by the complex and evolving relationships between internal and external influences (Carrillo-Hermosilla et al., 2010).

The primary drivers of eco-innovation identified in the literature can be grouped into three main categories: cost reduction, market opportunities, and policy measures (Gente and Pattanora, 2019). Within the latter, regulatory frameworks play a particularly influential role, as they can foster more radical forms of innovation compared to market-based mechanisms (Kemp and Pontoglio, 2011). Well-designed environmental regulations can stimulate innovation, offset compliance costs, and enhance competitiveness, making policy a crucial driver for eco-innovation uptake (Porter and van der Linde, 1995). Companies are compelled to comply with laws and regulations to gain legitimacy from governmental authorities. Moreover, they experience normative pressures, such as the

need to meet societal expectations around ethics and environmental responsibility, often emphasized by NGOs or local communities. Additionally, firms can be influenced by mimetic pressures, where they imitate the practices of competitors in order to remain competitive or to maintain legitimacy (Chen et al., 2018). Additional factors that support eco-innovation include education and capacity building, collaborative networks and partnerships, investment in research and development, and the use of public procurement as a strategic tool (Hazarika and Zhang, 2019).

Diffusion of innovations theory (Rogers, 2003) provides a valuable framework for understanding how innovations are adopted and disseminated within societies. In the eco-innovation literature, this framework is widely used to understand how eco-innovations diffuse. It posits that the rate and extent of adoption are influenced by five key attributes: *relative advantage* (the degree to which the innovation is perceived as superior to existing solutions), *compatibility* (the extent to which it aligns with the existing values, past experiences, and current needs of potential adopters), *complexity* (how difficult the innovation is to understand and use), *trialability* (the possibility to experiment with the innovation on a limited basis before full-scale adoption), and *observability* (the visibility of its results to others) (Kapoor et al., 2014). In the context of eco-innovation, these attributes interact with additional sustainability-specific factors such as environmental awareness, regulatory pressures, and societal norms. For instance, perceived relative advantage may encompass not only economic benefits but also environmental and social value creation, while compatibility may depend on alignment with sustainability goals or circular economy principles (Hazarika and Zhang, 2019). This theoretical lens thus helps explain why certain eco-innovations diffuse rapidly in some contexts but face resistance or slow uptake in others (Diaz-Rainey and Ashton, 2015).

3 Methods

This chapter begins by outlining the research philosophy that forms the foundation of this dissertation. It further outlines the two research methods applied in the four dissertation publications (see Table 2). For Publication I, a literature review was conducted, following the qualitative content analysis approach to provide a framework focusing on sustainability issues that arise throughout the life cycle of biobased plastic packaging products. This publication provides insights into the current state of the art in biobased plastic packaging, which is further analyzed in Publications II and III. An exploratory qualitative study is conducted using content analysis following abductive reasoning for the empirical papers. Publication II focused sustainability tensions, while Publication III examined the phenomenon of EOL-related lock-ins and their relation to eco-innovation diffusion. Publication IV focused on policy-led tensions in sustainability transitions by applying elements of MLP. Furthermore, this chapter outlines the key measures implemented to ensure the quality of this dissertation.

3.1 Research Philosophy

A research philosophy outlines the underlying assumptions about reality, knowledge, and values that shape the research process. These foundational ideas influence decisions made throughout all stages of the research process (Saunders et al., 2019, p. 130). They typically include *ontological* perspectives on the nature of reality, *epistemological* views on how knowledge is constructed and understood, and *axiological* considerations about how personal values might shape the research and its results. Collectively, these elements not only shape the methodological approach but also affect the selection of specific research methods (Guba and Lincoln, 1994; Saunders et al., 2019).

The research philosophy that best aligns with the foundational assumptions of this dissertation is critical realism, a paradigm that occupies the middle ground between the dominant traditions of positivism and interpretivism (Adamides et al., 2012; Bhaskar, 2014). In the field of sustainability transitions, critical realism is often adopted by researchers who underline the importance of innovations within their broader social contexts (Sorrell., 2018), in contrast to the positivist approach, which prioritizes the derivation of generalizable knowledge from isolated observations. At the same time, critical realism questions the interpretivist focus on subjective meaning, emphasizing that understanding social phenomena requires exploring deeper causal structures that are not always visible or accessible through interpretation alone (Zhang, 2023). Eco-innovation research is also considered to mostly have a critical realist approach focusing on the technology and the underlying mechanisms such as regulations and cultures within social structures. However, it can be claimed that eco-innovation diffusion research is often

solution oriented, resulting in its somewhat pragmatic nature (Elder-Vass, 2022). Integrating socio-technical transitions research into eco-innovation increases the interpretivism side by also analyzing how actors perceive and construct meanings around eco-innovations and how these meanings (discourses) create tensions. It should be noted that reflexivity is an essential factor in this research. While acknowledging that most eco-innovations are important for sustainability transitions, it is believed that this approach should not be taken as the guiding normative assumption. Hence, questioning whether eco-innovations are truly sustainable and under what conditions, taking different actors' views into account in terms of benefits and tensions, and acknowledging the trade-offs and complexity moves the research through a more reflexive approach.

This dissertation is grounded in a critical realist approach, which ontologically assumes that an objective reality exists independently of human perception. However, it also recognizes that this reality is mediated by individuals' interpretations, which shape how it is experienced and understood. From this standpoint, what we observe on the surface often stems from deeper, complex system dynamics. Uncovering the underlying structures and causal mechanisms behind observable events requires analytical attention to the less visible layers of these systems. In terms of epistemology, critical realism holds that while participants may offer subjective or biased perspectives, these accounts can still serve as valuable sources for developing insights into aspects of reality that are not directly observable. It also recognizes that knowledge of social systems is always open to reinterpretation, making both theories and findings inherently provisional. From an axiological perspective, critical realism acknowledges that research is inevitably influenced by the values and assumptions of the researcher. Yet, identifying and reflecting on these biases is essential to forming the most accurate explanations possible (O'Mahoney and Vincent, 2014). Methodologically, this philosophy promotes the use of approaches that uncover the deeper, contextual mechanisms underlying observable phenomena, often favoring qualitative or mixed methods over purely quantitative ones, which may not capture the full complexity of social reality.

3.2 Literature Review

A literature review serves as a critical synthesis of existing research, enabling scholars to identify, evaluate, and integrate relevant theoretical and empirical contributions within a particular field of study. By mapping the current state of knowledge, it provides a foundation for situating new research within established debates, recognizing gaps in understanding, and highlighting areas requiring further investigation (Booth et al., 2016). A well-conducted literature review goes beyond summarizing individual studies; it critically analyses methodological approaches, theoretical frameworks, and empirical findings to uncover patterns, contradictions, and emerging trends (Hart, 2018). In sustainability-related research, for example, literature reviews play a crucial role in consolidating interdisciplinary insights, drawing from environmental science, economics,

policy studies, and social sciences to inform both academic discourse and practical decision-making (Snyder, 2019). Such reviews not only ensure that research is informed by and contributes to scholarly conversations, but also enhance its credibility, coherence, and relevance.

Publication I examines the environmental, social, and economic risks associated with biobased plastic packaging throughout its life cycle by conducting a literature review. Scopus and Web of Science, two widely recognized academic databases for high quality research (Fahimnia et al., 2015), are utilized to identify relevant English-language publications from 2011 to April 2022. The search targeted articles that explicitly addressed sustainability challenges of bioplastics in packaging, with inclusion limited to peer-reviewed journal articles, book chapters, and conference papers. The set search words ((bio* plastic) AND packaging) AND (sustainab* OR environment* OR social OR econom*) AND (challenge OR risk OR drawback OR problem) are used.

An initial database search resulted in 344 results (156 from Web of Science and 188 from Scopus), which were reduced to 232 after removing duplicates. Abstracts and titles were screened for relevance to sustainability issues, narrowing the pool to 32 papers for full-text review. Of these, 29 met the eligibility criteria, and an additional five were identified through reference checks using a backward snowballing approach. In total, 34 articles formed the basis for the study's analysis of sustainability issues linked to biobased plastic packaging. These 34 papers were read in detail and analyzed qualitatively, following content analysis methodology (Miles and Huberman, 1994) in order to create the conceptual framework.

3.3 **Exploratory Qualitative Study**

Publications II, III, and IV follow an exploratory qualitative design, a methodological approach particularly suited for investigating phenomena that are complex, emerging, or not yet well understood. Exploratory research is often employed when the issue under study lacks established frameworks or extensive prior study, allowing for flexibility and openness in the research process (Eriksson and Kovalainen; 2008). The transition to sustainable packaging represents such a phenomenon, as it involves multiple stakeholders with diverse perspectives, practices, and interests, including businesses, consumers, municipalities, NGOs, academia, and waste management organizations. An exploratory qualitative approach enables the researcher to engage deeply with these varied experiences, capturing rich, contextualized insights that may not be accessible through quantitative or hypothesis-driven methods (Stebbins, 2001). By focusing on exploration rather than testing predefined assumptions, this approach provides the flexibility to identify unexpected patterns, emerging themes, and novel practices, which is essential in a field characterized by evolving regulations, business models, and consumer behaviors (Bryman, 2016). Furthermore, an exploratory qualitative design supports an iterative investigation, allowing the research to adapt as new insights emerge and to connect

empirical findings with relevant theoretical frameworks in a reflective and context-sensitive manner (Eriksson and Kovalainen; 2008).

3.3.1 **Data Collection**

In Publications II, III, and IV, a semi-structured interview guide with open-ended questions was used to provide structure while allowing participants to freely express their views (Eisenhardt, 1989). In-depth semi-structured interviews were utilized to capture detailed insights into the participants' perspectives and to explore diverse opinions comprehensively (Denzin and Lincoln, 2011; Kvale and Brinkmann, 2009). During the selection of appropriate interviewees, besides the steps explained below, further participants were recruited using a snowball sampling approach, where existing informants suggested other knowledgeable contacts (Parker et al., 2019). All the participants were invited via email or LinkedIn messages to join virtual meetings conducted on Microsoft Teams. All the interviews were recorded and transcribed for analysis. To enhance the credibility of the findings and add depth to the dataset (Creswell, 2006), supplementary sources such as company websites, blogs, and various reports (including sustainability, action, and annual reports) were consulted to complement the primary interview data in Publications II and III. In Publication IV, policy documents, corporate websites, blog content, company, NGO, and municipality publications were consulted to complement the primary interview data.

In total, 47 unique interviews were conducted by Deniz Turkcu. In Publication II, data was collected from 14 companies representing various stages of the biobased plastics packaging supply chain, including monomer and polymer producers, converters, packaging manufacturers, wholesalers, and end-product users (brand owners). Including companies from multiple supply chain positions provided a comprehensive understanding of operations across the sector. To identify relevant firms, a Google search was employed using keywords such as "biobased plastic packaging companies," "biobased companies," "biobased plastic packaging sector," and "bioplastic companies." This search was supplemented by reviewing LinkedIn groups (e.g., "Bioplastics: Compostable, Biodegradable & Biobased Plastics," "Biomass 4 Biobased Products," "BioBased Economy") and industry association websites (e.g., European Bioplastics e.V., Biodegradable Plastics Association) to identify additional companies. Information about the identified companies was recorded in an Excel sheet, including details such as supply chain stage, company size, and country of origin. Companies were contacted with the aim of ensuring diversity in terms of supply chain position, country, and product type, with most companies operating within the EU and a few from other countries to enhance data variation. Interviewees were chosen based on their expertise and knowledge of sustainability topics, prioritizing sustainability professionals or otherwise the most informed company representatives.

The interviews were carried out between June and August 2022, lasting 30–80 minutes each, resulting in a total of 761 minutes of recorded data. Interviews began with questions about the participants' understanding of sustainability issues in biobased plastics and

sustainable packaging, challenges encountered, company-specific experiences, and potential mitigation strategies.

In Publication III, 24 semi-structured interviews were conducted with firms engaged in the biobased plastic packaging (BBPP) sector. Companies were located through searches of industry association directories (e.g., European Bioplastics e.V.), LinkedIn groups (e.g., BioBased Economy), and keyword searches including "biobased plastic packaging," "biobased companies," and "biodegradable biobased plastics". Participants were selected based on their involvement and expertise, with preference given to those most familiar with sustainability-related activities within their organizations. Data collection took place in 2022 and 2024 and involved 24 expert interviews (14 were the same as in Publication II + 10 new) with representatives of companies predominantly active in the BBPP field. To broaden the scope of perspectives, three firms working on non-biodegradable biobased materials and one consultancy were also included. These actors were considered highly knowledgeable about biodegradable biobased plastics, contributing valuable insights for the research. Interviews were conducted until theoretical saturation was reached, resulting in a total of 1,159 minutes of material.

The interviews were guided by a thematic structure covering five main areas: (i) sustainability benefits, challenges, and issues related to biodegradable biobased plastics and sustainable packaging; (ii) end-of-life processes and sectoral challenges; (iii) industry development, market outlook, and external drivers; (iv) initiatives to promote diffusion; and (v) anticipated developments at both company and market levels.

In Publication IV, a total of 33 semi-structured expert interviews were carried out online between June and September 2023. The study focused on stakeholders directly engaged in the transition driven by this specific policy, including NGOs, pooling system providers, researchers in the field of reusable packaging, municipalities, waste management organizations, and cleaning service providers collaborating with restaurants in reusable cup cleaning. Germany is chosen as the case context as it is the first country to introduce this obligation, providing a unique opportunity to observe systemic tensions that emerge at the early stage of policy-driven transitions. Examining Germany's pioneering role allows the study to capture the tensions it triggers, offering insights that are highly relevant for other countries considering similar policies. Potential participants were identified through Google searches using terms such as "reusable packaging Germany," "Mehrwegangebotspflicht," "reusable cups Germany," "mandatory reusable packaging," and "obligation to offer reusable packaging Germany." In addition, members of networks and associations promoting reusable packaging, such as *Mehrwegverband Deutschland e.V.*, were screened to locate further relevant experts. Participants were selected based on their active engagement in the field and recognized expertise, with priority given to individuals acknowledged as central knowledge holders within their organizations. Altogether, the interviews amounted to 1,484 minutes.

The interview guide was structured around five key themes: (i) general perceptions of reusable packaging for takeaway food in the gastronomy sector; (ii) views on the policy,

its implementation, and societal impacts; (iii) main challenges and barriers affecting effective implementation and positive outcomes; (iv) current and future strategies for addressing these challenges; and (v) further recommendations for mitigation actions that could be undertaken by different stakeholders.

3.3.2 **Data Analysis**

Publications II, III, and IV follow a qualitative structured content analysis approach, drawing on the principles outlined by Miles and Huberman (1994). This process involved several steps: initially reducing the transcribed data with the support of NVivo software, then organizing and presenting the information, and finally interpreting and validating the findings. The abductive approach is utilized during data analysis, which is particularly suitable for studying complex and evolving socio-technical phenomena such as the transition to sustainable packaging systems. Abduction, as distinct from pure induction or deduction, is characterized by a continuous interplay between empirical material and theoretical concepts (Timmermans and Tavory, 2012; Dubois and Gadde, 2002). While inductive research builds theory solely from data (Andreewsky and Bourcier, 2000; Danermark, 2001; Taylor et al., 2002) and deductive research tests predefined hypotheses derived from theory (Arlbjørn and Halldórsson, 2002), abductive reasoning enables the researcher to move iteratively between the two, developing interpretations that are both empirically grounded and theoretically informed. This iterative back-and-forth process between theories is especially valuable in underexplored contexts, such as the tensions in sustainable packaging where established theories may only partially capture the complexities at hand, and novel insights are needed to extend or refine theoretical understanding (Dubois and Gadde, 2002; Timmermans and Tavory, 2012). Thus, the abductive approach positions the researcher not as a neutral observer but as an active interpreter, weaving together empirical observations and theoretical perspectives in order to generate nuanced explanations of how actors understand and navigate the challenges of system change (Alvesson and Kärreman, 2007; Reichertz, 2010).

In practice, this means that the analysis began with close engagement with the qualitative data, allowing categories and themes to emerge through coding in a relatively open and inductive manner (Corbin and Strauss, 2015). At the same time, existing theoretical lenses provided sensitizing concepts that guided the interpretation of empirical patterns without imposing rigid structures on the analysis. In Publication II, open coding (Miles et al., 2014) was applied to the textual data to uncover the impacts, issues, and challenges in sustainable packaging; as well as the management strategies being utilized by companies. Challenges were examined and categorized by their characteristics as “tensions,” following the definition of tensions from the literature. Later on, tensions were grouped into broader theory-informed themes (such as economic, behavioral, psychological, and institutional) to form a framework. Afterwards, from management strategies, subcategories such as participation in associations and business model innovation were identified. Subsequently, these identified subcategories were put into bigger categories (such as the synthesis strategy, acceptance strategy, separation strategy) in the light of

paradox theory. Lastly, the results of the tensions and their management techniques were linked.

In Publication III open coding was utilized as the first step to extract the core EOL challenges, the underlying drivers of these issues, and preliminary ideas for potential solutions or activities. As the coding developed, it became evident that many of these challenges were tied to forms of EOL lock-ins. Building on this observation, the identified lock-ins were grouped into four overarching categories of technological, institutional, discursive, and behavioral; drawing support from the literature. After categorizing the lock-ins, an additional interpretive stage was introduced to apply the innovation diffusion framework to examine how the lock-ins and their effects could be interpreted through perspectives of innovation, adopters, innovators, and environmental or infrastructural conditions. After this, strategies to address and overcome these constraints were categorized through open coding. Finally, the insights were synthesized into concrete recommendations tailored to the characteristics of each lock-in, outlining practical ways to address diffusion barriers and enable systemic change.

In Publication IV, open coding started to capture the main challenges expressed by participants, along with the potential strategies they suggested to address them. As the coding progressed, it became evident that these challenges stemmed from tensions between different actors. These tensions were subsequently organized into four broad categories, informed by the literature: economic, structural, psychological, and behavioral. To further enrich and situate the analysis, the tensions were interpreted through the socio-technical dimensions of the MLP. These included aspects such as technology, user practices and market applications, cultural and symbolic meanings, infrastructure, industry organization, and policy. Additional governance-related issues were also highlighted, including unclear allocation of resources, insufficient bureaucratic capacity, and weak policy coordination. The final step synthesized the interview findings into suggested actions for policymakers, industry representatives, and other stakeholders, outlining practical measures for addressing the identified tensions.

To enhance external validity, the analysis followed a triangulation approach. The interview transcripts were first analyzed independently by two researchers, after which the findings were cross-verified and consolidated as well. This process reduced individual bias and ensured greater consistency and robustness in the interpretation of the data (Denzin, 1978; Patton, 1999; Creswell, 2014).

Table 2: Summary of Data Collected and Analyzed in the Empirical Publications

Publication 1	Publication 2	Publication 3	Publication 4
Primary Data:	Primary Data:	Primary Data:	Primary Data:

keywords: ((bio* plastic) AND packaging) AND (sustainab* OR environment* OR social OR econom*) AND (challenge OR risk OR drawback OR problem) 344 articles with the initial search in Scopus and Web of Science 34 chosen articles based on the inclusion of TBL and life cycle management perspectives	14 semi-structured company interviews with: - 5 sustainability managers/directors - 4 CEE, COO or CFOs - 2 program, project, or business directors - 2 technical managers - 1 business development or marketing manager Interview length: 30–80 min (total 761 min) <u>Secondary data:</u> Blogs, websites, sustainability reports, corporate reports, newsletters	24 semi-structured company interviews with: - 7 sustainability manager/directors - 3 project managers - 6 CEE, COO or CFOs - 3 program, project or business directors - 2 technical managers - 3 business development or marketing managers Interview length: 30–80 min (total 1159 min) <u>Secondary data:</u> Blogs, websites, sustainability reports, corporate reports	33 semi-structured expert interviews from: - 6 pooling system providers - 1 social business - 12 NGOs - 5 municipalities - 1 government official - 1 freelancer - 1 cleaning system provider - 1 waste management company - 5 academic institutions Interview length: 21–68 min (total 1484 min) <u>Secondary data:</u> Blogs, websites, NGO, company, municipality and government reports, policy documents
Data collection timeframe: first round: November 2021, second round: March 2022	Data collection timeframe: June–August 2022	Data collection timeframe: June 2022–November 2024	Data collection timeframe: June–September 2023
Research design: Literature review	Research design: Exploratory qualitative study	Research design: Exploratory qualitative study	Research design: Exploratory qualitative study
Data analysis methods: content analysis	Data analysis methods: content analysis following abductive reasoning	Data analysis methods: content analysis following abductive reasoning	Data analysis methods: content analysis following abductive reasoning

3.4 **Quality Criteria**

Healy and Perry (2000) introduced six criteria to assess the validity and reliability of research conducted within the critical realist framework. These criteria correspond to

three key elements of the paradigm. For ontology, the criteria are (1) "ontological appropriateness" and (2) "contingent validity," which ensure the research's alignment with critical realist views of reality. The epistemological criterion is (3) the recognition of "multiple perceptions from both participants and peer researchers," acknowledging that understanding the unobservable real world relies on subjective, value-influenced interpretations. This awareness guides the research design to address potential biases and errors in data. The methodological criteria include (4) "methodological trustworthiness," (5) "analytic generalization," and (6) "construct validity," all of which focus on ensuring the robustness of the research methods. Table 3 outlines the main steps taken to uphold the quality of this dissertation.

Table 3: Overview of actions implemented to uphold standards of research quality

Elements	**Quality criterion**	**Measures applied to ensure quality criteria**
Ontology	**Ontological appropriateness** Assumptions that the research explores intricate social dynamics involving individuals who are capable of reflection and interpretation	• The dissertation is explicitly centred on exploring *how* to address the complexities involved in sustainable packaging. • A purposive sampling strategy was utilized to choose interview participants, targeting experts with varied professional backgrounds, spanning different companies, organizations such as academia, NGOs, municipalities, and government workers in different roles and geographical locations to obtain rich, multi-perspective insights into the topic under investigation.
	Contingent validity Assumptions that observable phenomena are the result of deeper, often hidden, mechanisms at work in the world.	• Contexts were deliberately chosen to allow for the clearest possible observation and understanding of the underlying causal mechanisms related to the phenomena under study. • Emphasis on the *why* questions in semi-structured interview guides *how* in order to gain a deeper understanding of the observed phenomena.
Epistemology	**Multiple perceptions of participants and peer researchers** Awareness that understanding the real world requires engaging with inherently biased and value-laden human perceptions	• Expert interviews were complemented with secondary sources such as corporate publications, sustainability reports, and online content to enable triangulation of data and methods. • Data analysis and interpretation were collaboratively conducted by multiple researchers to enhance reliability and reduce individual bias. • Ongoing self-reflection was practiced throughout the research process to recognize and minimize the influence of personal values. • Efforts were made to remain mindful of and explicitly acknowledge potential Eurocentric perspectives that may have shaped the findings.

Methodology	**Methodological trustworthiness** Ensure credibility by making the research process transparent and open to external review and evaluation	• Detailed explanation of the chosen methodological strategies was provided. • All semi-structured interviews were transcribed and securely archived. • Interview transcripts and related archival materials were systematically organized within an NVIVO project file. • Each step of the qualitative analysis process conducted in the context of the literature review was designed to be fully transparent and reproducible. • Representative quotations from both interviews were included in the empirical study write-ups to support the analysis and enhance credibility.
	Analytic generalization Emphasis on developing theoretical insights instead of testing existing theories through statistical methods	• Application of a qualitative, abductive research design, where theoretical concepts functioned primarily as overarching themes to help organize findings that emerged inductively from the data. • Development of interview protocols aimed at gathering information that could either support or challenge pre-existing theoretical assumptions. • Adaptation of theoretical frameworks commonly used in other academic fields to explore their relevance in new empirical settings, with the aim of generating fresh theoretical contributions.
	Construct validity Ensure the precision and validity of the developed theoretical concepts and resulting insights	• Semi-structured interview protocols were developed drawing on established theoretical frameworks and concepts from the literature. • The research process included reflective consideration of the researcher's own role and attention to alternative interpretations of the findings. • Multiple data sources were triangulated, including interviews, company documents, sustainability reports, and websites, to enhance credibility. • The findings were presented with rich contextual detail to provide a comprehensive understanding of the observed phenomena.

4 Summary of the Publication and Results

This chapter elaborates the main results of the three publications that comprise this dissertation.

4.1 Publication 1: A Conceptual Framework of the Sustainability Challenges Experienced during the Life Cycle of Biobased Packaging Products

4.1.1 Background and Objectives

Biobased plastic packaging (plastic packaging derived from renewable resources like sugarcane and corn) is created in order to tackle the sustainability challenges conventional plastic packaging creates and to decrease the dependency on fossil fuels (Molina-Besch and Keszleri, 2022). However, the existing body of literature highlights that these products also have many sustainability problems, such as land use change from food production to biomass production, health and safety issues in production, and EOL-related problems due to consumer awareness and lack of infrastructure. As the demand for sustainable packaging grows, driven by the pressure coming from consumers and regulations, production and consumption of these products are also expected to grow. In order to address and mitigate the mentioned sustainability challenges, it is important to understand them in detail and in a holistic way. Even though the sustainability concerns of BBPPs are acknowledged, there are very few literature review studies (e.g., Gerassimidou et al., 2021; Spierling et al., 2018) that analyze these issues in a holistic way considering the economic, environmental, and social sustainability dimensions, especially including the social dimension and considering the whole value chain. Also, most studies are based on the challenges of these products compared conventional plastic packaging alternatives. Even though these products are created to replace mainly conventional plastic packaging, they can also be used instead of paper or glass packaging. Hence, while studying these challenges, going beyond the comparison to a specific alternative is important. Moreover, there is a need for research that goes beyond analyzing and summarizing these issues through a literature review by illustrating how various challenges may intersect across multiple sustainability dimensions and life cycle stages; for example by creating a conceptual framework as in this study. Conceptual frameworks are essential for building upon the literature review to define and illustrate the relationships among key concepts, guiding the research design (Rocco and Plakhotnik, 2009).

Publication I aims to address this gap by conducting a literature review of 34 selected papers out of the 232 articles screened in order to create a conceptual framework. The following research questions are answered in the publication:

1- What are the main environmental, social, and economic challenges associated with biobased packaging products in their different life cycle stages?
2- What are the missing parts and emerging themes in the current literature on the sustainability of biobased packaging products?

4.1.2 **Results and Contributions**

The result of this study is the creation of a conceptual framework (See Table 4) by categorizing the economic, environmental, and social sustainability issues of BBPPs among their life cycles, considering the beginning of life (resource extraction), middle of life (production and use), and end of life, as well as some general challenges through a literature review. Moreover, this provides the state of the art of research examining sustainability challenges of BBPPs and reveals the gaps in the literature.

Results indicate that the sustainability of bio-based plastic packaging is influenced by several factors, including the type of feedstock used, agricultural practices during biomass cultivation, available EOL management options, and consumer awareness regarding proper disposal methods. Moreover, it has been recognized that sustainability challenges across different domains can influence and interact with one another. For example, environmental issues like resource extraction and decreased water security can create problems in human health that can further cause economic issues related to workforce capacity and human capital. It makes theoretical contributions and goes beyond the state of the art by categorizing the sustainability issues in life cycle phases, by connecting the issues in different sustainability dimensions to each other and underlining the social sustainability issues. Furthermore, it provides recommendations to the companies highlighting the challenges associated with biobased plastic packaging products without making comparisons to alternative packaging options. Lastly, it underlines the importance of further developing different tools to evaluate the sustainability impacts of BBPPs in a holistic way.

Table 4: A conceptual framework of challenges of biobased (plastic) packaging products (adapted from Publication I)

	Environmental	**Economic**	**Social**
Phase 1: Beginning of life: Resource Extraction	• Land use change decreasing space for food • Toxic pesticide and fertilizer use can create pollution • Soil erosion and deforestation	• Possible increase in food prices with land use change	• Toxic pesticides causing risk to human health • Risk of exploitative working conditions in developing countries as they have low social standards

	• Eutrophication • Use of GMOs • Potential hazard in the workplace • Decreasing water security • Land use change increasing carbon emissions		• Alienation and negative impacts on livability • Land use change can alter ecosystems, increasing risk of zoonotic and infectious diseases
Phase 2: Middle of Life: Production	• Efficiency in the use of water and energy	• Because of the small market, redesign of production not being viable	• Occupational health and safety hazard problems
Phase 3: Middle of Life: Use	• Use of hazardous chemicals or petroleum-based co-polymers during production and processing		• Low willingness to pay • Low demand • Consumers preferring other types of packaging • Added chemical substances during production can migrate from packaging to food and can cause human health problems
Phase 4: End of Life	• PET streams being contaminated with PLA causing poor quality recycled PET • Non-existing standards about biodegradability in water • Lack of sorting infrastructure • Lack of biodegradation/composting/recycling infrastructure • Some packaging not degrading in marine environment for a long time • Degradation of biodegradable plastic increasing GHG emissions when disposed into landfills	• Because of the small market, redesign of waste management system not being viable	• Differences in waste management systems in different areas and countries • Consumers not knowing how to separate waste • Labeling not being clear and reliable • Compostability claims as a license to litter • Biodegradation of certain plastics can release toxic substances that can create risks to human health

	• Biodegradable materials contaminating organic solid waste treatment • Biodegradation of certain plastics can release toxic substances that can pollute environment		
General	• Certification/label not being clear • Not being necessarily sustainable • No viable option that can meet performance criteria and is cost effective • Circular economy debate on biodegradability		

4.2 Publication 2: The Dark Side of Sustainable Packaging: Battling with Sustainability Tensions

4.2.1 Background and Objectives

Sustainable packaging products pose a range of sustainability challenges, besides their beneficial outcomes and win-win situations in manufacturing, transportation, EOL, and raw material extraction phases. These challenges are conceptualized as tensions in the CSR literature; conflicts between interconnected and interdependent economic, environmental, and social goals, motivations and interests (Hahn et al., 2015) that manufacturers of sustainable packaging and relevant stakeholders must navigate. These tensions stem from the participation of a wider and more complex range of actors and decision-makers, alongside broader stakeholder and supply chain networks. In order to navigate these tensions, their characteristics, complexity and variety need to be analyzed in detail. Tensions are categorized as economic, structural, psychological, and behavioral tensions, following the marketing literature (Tóth et al., 2018). Existing research recognizes the necessity for empirical research to better comprehend the different kinds of tensions and to develop effective approaches for managing them. In the paradox perspective literature, tensions are known to be managed by embracing and acknowledging that they can coexist and be balanced (Brix-Asala et al., 2018). It allows companies to pursue conflicting sustainability goals simultaneously by utilizing acceptance, separation, and synthesis strategies.

Biobased plastic packaging products are understood to be an emerging industry; an initiative that is at a nascent stage or in the early phase of maturity, characterized by ongoing learning and efforts to achieve stability (Forbes and Kirsch, 2011). Emerging industries have extra complexities and tensions compared to established industries due to the high uncertainty, development challenges like limited raw material access, high upfront costs, inadequate infrastructure, and low consumer trust (Porumboiu, 2020).

Previous literature investigated these tensions mostly in terms of technical challenges, leaving sustainability tensions understudied. Moreover, most of the previous studies are at the producer level, leaving a gap in holistic studies of the overall life cycle of these products.

Understanding the context and literature gaps, Publication II investigates 14 companies across eight countries across various roles within the biobased plastics packaging supply chain through a qualitative explorative study. It aims to identify and categorize tensions following CSR literature and tension management strategies through a paradox lens in the life cycle of the biobased plastic packaging industry, conceptualized as an emerging industry. The following research questions are answered in the publication:

1- What are the characteristics of the tensions of sustainable packaging production?
2- How can companies manage such tensions in an emerging and innovative industry?

4.2.2 **Results and Contributions**

The study categorizes the economic, structural, psychological, and behavioral tensions, and it further identifies 20 types of tension subcategories and 12 strategies businesses utilize to manage them.

The main economic tensions are identified as high investment and operating costs needed for development of technology, infrastructure, management, innovation, and product testing; creating barriers for market entry and operation. From the consumer perspective, higher or uncertain prices reflect the extra costs incurred through sustainable material choices and process modifications. Moreover, ongoing technological development means sustainable packaging often offers reduced functionality or performance compared to traditional alternatives like plastics.

Structural tensions stem from producers facing operational challenges due to lacking standards and guidelines for production and EOL processes, complicating sustainability management. Customers also struggle with EOL handling without clear instructions, sometimes leading to incorrect disposal or reluctance to purchase sustainable products. Additionally, producers contend with inconsistent taxation policies and outdated regulations across regions, creating difficulties in balancing different management and operating activities. Decision-making within the industry is hindered by conflicting views on responsibility for systemic changes, such as infrastructure, land degradation, and standard setting.

The key psychological tensions in the industry revolve around political risk and financial concerns, which are closely linked. Frequent changes in laws and regulations create uncertainty for manufacturers, making it difficult to predict future industry standards and

requiring ongoing investment to comply with evolving rules. Producers worry that policymakers lack the necessary expertise to regulate the market effectively, potentially leading to harmful or inappropriate regulations. Consumers often fear greenwashing, which threatens the financial stability of the businesses in the industry. Similarly, EOL operators fear contamination risks in their processing streams due to their limited understanding of these new products, complicating the development of effective disposal and recycling methods.

Tensions arise across various actors, with governments and producers needing to educate consumers and EOL operators about product use and disposal amid conflicting views on best practices. The industry also contends with trade-offs between sustainability goals, technological uncertainty, and short- versus long-term priorities, such as reliance on hazardous materials and high resource use in production, as well as environmental costs from transporting renewable raw materials over long distances.

Companies use various tension management strategies to address conflicting challenges, including acceptance, separation, and synthesis approaches. While many accept limitations, such as waste management companies' reluctance to handle new products, some actively innovate by creating recycling ecosystems, partnering with others, localizing supply chains, and developing new business models. To address structural tensions like lacking standards, companies join industry associations to push for systemic change and consensus. Psychological tensions, such as fears of greenwashing, are managed through due diligence, customer selection, advisory services, and education efforts aimed at consumers and composters. Firms invest in research, certifications, and communication to meet higher disclosure demands and improve transparency. Despite these efforts, compromises remain necessary, with companies prioritizing environmental concerns over financial ones by adopting costlier production methods or investing heavily in sustainable innovations and recycled materials.

This research adds to the limited existing body of knowledge on the dark side of sustainability, and responds to the call for empirical studies on the unintended consequences of sustainable production and associated management practices by being the first study in BBPPs. It integrates CSR literature by tension definition, categorization and conceptualization as well as paradox management theories. It underlines the tensions at industrial and societal levels besides the corporate level, and highlights the responsibilities and duties of government in decision-making processes. It gives recommendations to the companies to anticipate upcoming sustainability tensions to proactively prepare and develop solutions, reducing exit rates and encouraging new entries, which in turn can accelerate the growth of the emerging industry.

4.3 Publication 3: The Role of End-of-Life Lock-ins in the Diffusion of Eco-innovations

4.3.1 Background and Objectives

Eco-innovations are known to have the potential to address global sustainability challenges by promoting resource efficiency, reducing environmental impacts, and enabling systemic shifts toward more sustainable production and consumption patterns. Yet, they face difficulties in achieving mass market adoption due to their inherent complexity, uncertainty, involvement of diverse stakeholders and their conflicting interests (Clausen and Fichter, 2019), and strong competition from incumbent technologies that are deeply embedded within existing societal structures (Geels, 2002; Köhler et al., 2019). The socio-technical perspective on lock-ins highlights how co-evolved political, social, and technological factors such as dominant designs and entrenched infrastructures impede system transformation. Such systemic lock-ins can inhibit the transition toward more sustainable alternatives. However, a gap in the literature is identified regarding the combination of eco-innovation diffusion and sustainability transition literatures, such as socio-technical lock-ins (Hazarika and Zhanh, 2019) that can enable in-depth analysis of the barriers to eco-innovation diffusion and adoption by revealing the broader interconnections and the holistic structure underlying these challenges.

One particularly critical area in eco-innovation diffusion is the management of EOL processes, including recycling, disposal, and resource recovery, which often remain underdeveloped or poorly integrated. Addressing these EOL-related challenges not only improves operational feasibility but also enhances the credibility, perceived value, and trustworthiness of eco-innovations among consumers and stakeholders and as a result, significantly helps with the wider diffusion of eco-innovations (Aldieri and Vinci, 2021). However, despite its critical role, the EOL phase remains underexplored in eco-innovation diffusion research (de Jesus and Mendonça, 2018).

In order to address these gaps, Publication III aims to identify the EOL-related lock-ins and further analyze these lock-ins utilizing the innovation diffusion framework (Bessant and Tidd, 2007; Rogers, 2003) in order to understand the reasons causing and strengthening these lock-ins that hinder eco-innovation diffusion. This study conducts qualitative research through 24 semi-structured interviews with companies operating in the biodegradable biobased plastic packaging product and closely-related biobased nonbiodegradable sector. Biodegradable biobased plastic packaging products are made from renewable biological origins (e.g., plant-based feedstocks) that are engineered to decompose via natural microbial activity into water, carbon dioxide, and biomass under defined environmental conditions and timescales. EOL management processes for these products include collection, recycling, composting, and disposal (Gerassimidou et al., 2021). Persistent challenges are exacerbated through fragmented standards, unclear

labeling, limited consumer awareness, and lack of infrastructure (Gerassimidou et al., 2021; Molina-Besch, 2022).

Through conceptualizing biodegradable biobased plastic packaging products as eco-innovations, the following research questions are answered in the publication:

1- What is the relationship between eco-innovation diffusion and EOL lock-ins?
2- How can the innovators overcome challenges related to eco-innovation diffusion that contribute to the EOL lock-ins?

4.3.2 **Results and Contributions**

The dominance of conventional plastics in EOL management is identified as being reinforced by technological, institutional, behavioral, and discursive lock-ins. Technological lock-ins arise from economies of scale, established technological learning, existing infrastructure, and higher consumption rates that lower the costs of managing conventional plastics compared to emerging biobased and biodegradable plastic products. As a result, businesses and governments find it financially risky to invest in alternative packaging solutions' EOL management. Institutional lock-ins include entrenched policies, waste management systems, and powerful industry actors with a high market share and lobbying power that favor conventional plastics, creating significant barriers for alternatives. Behavioral lock-ins stem from consumer habits and risk aversion, maintaining reliance on familiar disposal and recycling practices, while key waste processors such as recyclers and composting facilities often resist integrating BBPPs due to perceived disruptions. Finally, discursive lock-ins manifest in the widespread association of sustainability with recyclability, marginalizing BBPPs and limiting public and policy support for alternative EOL approaches like biodegradability.

Identified EOL lock-ins are further analyzed through the innovation diffusion framework in terms of innovation, innovator, innovation adaptor, and environmental and infrastructure characteristics. Figure 3 provides an overview of the findings derived from the analysis.

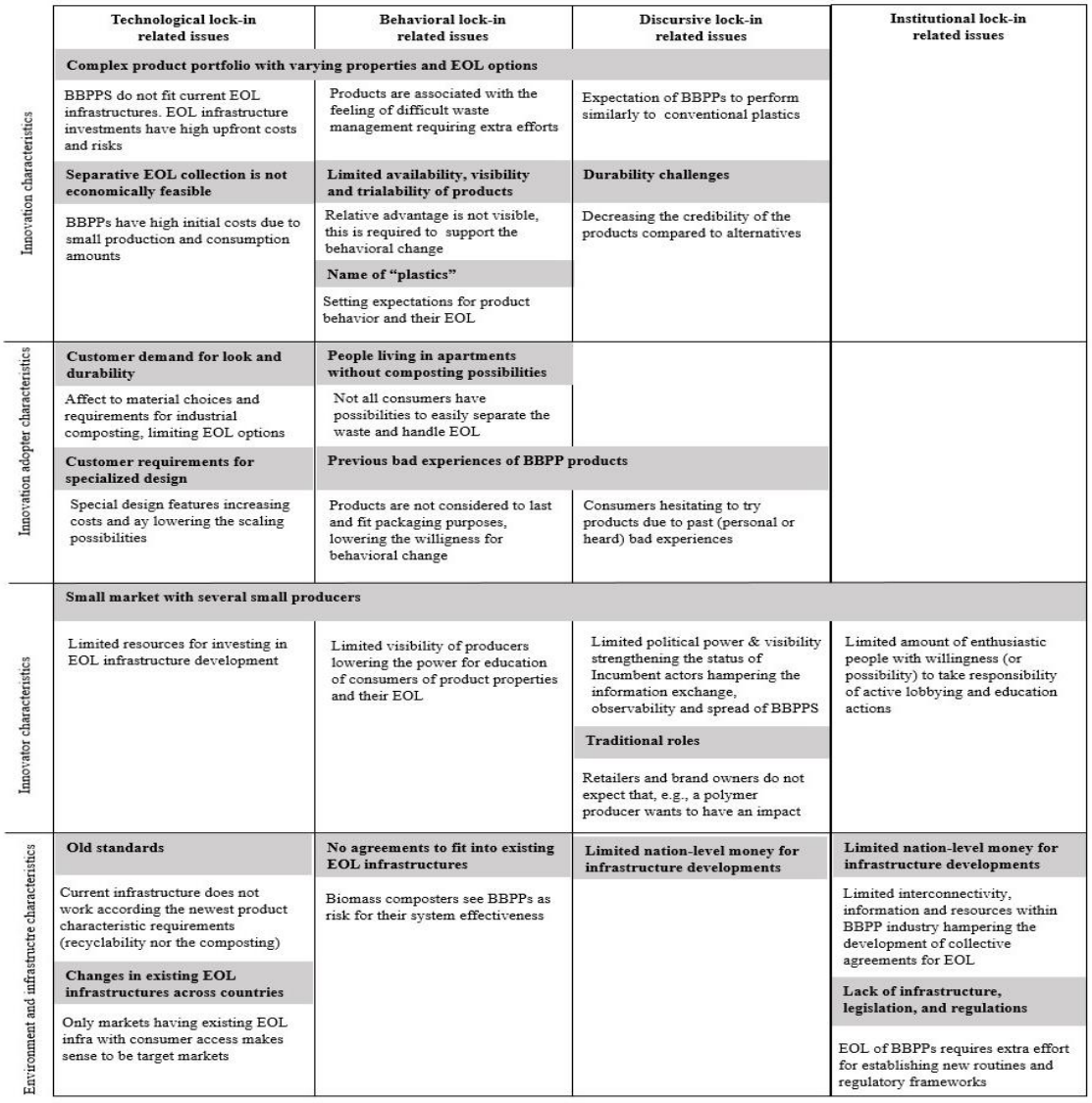

Figure 3: Analyzing EOL lock-ins through the innovation diffusion frame (adapted from Publication III)

Lastly, viewing the diffusion of biobased and biodegradable plastic products through innovation diffusion theory highlighted key action areas companies are taking to overcome EOL lock-ins. The findings fall into five main categories: design and technological development, marketing, process optimization and lobbying, education, and communication.

A key contribution of this study is the identification of specific lock-ins within the EOL management of BBPPs that hinder their diffusion. While earlier research (e.g., Cecere et

al., 2014; Simoens et al., 2022; Seto et al., 2016) recognizes general lock-ins in sustainability transitions and connects EOL to eco-innovations, this study uniquely highlights EOL-related lock-ins as key barriers. This paper contributes to the eco-innovation diffusion literature (Clausen and Fichter, 2019; Karakaya et al., 2014; Keränen et al., 2023) by adopting a holistic perspective and highlights the importance of EOL management in eco-innovation literature (de Jesus and Mendonça, 2018). It also addresses the gap identified by Aminoff and Sundqvist-Andberg (2021) on the need to examine individual-level factors behind system-level lock-ins.

4.4 Publication 4: Addressing Tensions Within a Policy-led Transition from Single-use to Reusable Packaging in Takeaway Food Sector in Germany

4.4.1 Background and Objectives

Despite environmental policy interventions for sustainability transitions being seen as essential, the successful implementation of such policies often encounters tensions due to the complexity of socio-technical regimes and the interplay of diverse actor interests, norms, and practices (Geels, 2011). Understanding these tensions is critical for identifying barriers to transitions and improving the design and implementation of policy instruments.

Single-use packaging in the food and beverage sector is seen as problematic, as it contributes to pollution, resource inefficiency, and increased public waste management costs (Dorn and Stöckli, 2018; Maye et al., 2019). In response, Germany has enacted a pioneering regulation under the amended Packaging Act (VerpackG), mandating gastronomy businesses to offer reusable containers for takeaway services starting in 2023 (German Federal Ministry of Justice, 2023). This policy has catalyzed a system-wide transition involving diverse actors including municipalities, businesses, reusable system providers, and consumers that resulted in new business models and needs in infrastructures and behavioral shifts. Initial implementation has exposed various systemic challenges such as lack of capacity, fragmented responsibilities, insufficient information, and motivational barriers among stakeholders (Theobald et al., 2024). Publication IV aims to investigate the tensions arising from the reusable packaging mandate in Germany, using a framework that integrates the MLP with tension typologies from the CSR literature. These typologies include economic, structural, psychological, and behavioral tensions (Hahn et al., 2015; Turkcu and Tura, 2023).

While sustainability transitions are acknowledged as deeply political and policy-driven processes, there is a gap in the literature for insufficiently addressing the outcomes and tensions generated by such policies (Köhler et al., 2019) and the tensions they may create in different contexts (Jørgensen, 2012). Moreover, while the multi-level perspective

(MLP) has been extensively used in sectors like energy, mobility, and agri-food, its application within the packaging sector is still relatively underexplored (Beswick-Parsons et al., 2023). The literature highlights the significance of combining the MLP with actor-level analyses (Avelino and Wittmayer, 2016), since the success of system change depends on the engagement, leadership, support, and acceptance of various actors whose decisions and interactions influence the direction and outcome of the transition (van den Broek et al., 2024).

In order to refer to the literature gaps in the context, 33 semi-structured expert interviews from stakeholders involved in the implementation of reusable packaging systems, including municipal officials, NGOs, pooling system providers, waste managers, and academics were conducted. This study addresses two key research questions:

1- What kind of tensions arise when a new policy is introduced into the system of reusable packaging?
2- What kind of strategies actors can utilize to cope with (/overcome) the tensions?

4.4.2 **Results and Contributions**

Publication IV identifies four categories of tensions—economic, structural, psychological, and behavioral—faced by a wide range of stakeholders including restaurants, consumers, municipalities, pooling system providers, and cleaning companies in this policy-led transition. These tension categories are analyzed in light of the MLP elements: technology, user practices and application domains (markets), symbolic meaning of technology, infrastructure, industry structure, policy and techno-scientific knowledge. Examining the tension dynamics through the lens of the MLP framework helps to provide a deeper understanding of their underlying causes and their influence on broader sustainability transitions. Lastly, this study analyzes proposed mitigation strategies to mitigate the analyzed tensions.

The results indicate that economic tensions revolve around increased operational costs of restaurants in subscription and cleaning fees, and consumer resistance to deposits or rentals of the reusable business models. Both consumers and restaurants face challenges with technology and knowledge, including reduced functionality and performance. Reusable products often have issues like leakage, limited durability, and inconvenient sizes due to limited scientific understanding. Structural tensions are shaped by ambiguous responsibilities, lack of unified return infrastructure, and lack of clarity in the policy, with municipalities having issues about understanding and resources to enforce regulations. Moreover, restaurants face a growing regulatory burden, struggling to comply with numerous post-COVID rules with inconsistent policies and poor coordination, such as conflicting health and packaging regulations while lacking the resources, support, and guidance needed to adapt effectively. Psychological and behavioral tensions further complicate the transition, including possible hygiene and health issues related to the

cleaning of products and microplastics concerns consumers, digital exclusion of elderly citizens, user habits, negative symbolic/cultural meanings around reusable products, and fear of pooling system providers that hinder adoption and repeated use. Moreover, policymakers are reluctant to propose stricter policies, while municipalities hesitate to enforce them due to concerns about losing electoral support.

In order to mitigate these issues, offered strategies revolve around providing funds and resources to municipalities, setting standards, research and development (R&D) investments to improve product functionality, unified nationwide education and marketing about the policy and reusable packaging products and systems, developing return infrastructure that allows products from different pooling system providers to be returned to the same location, utilization of centralized washing services for the returned products by gastronomy actors, and providing financial aids and incentives to restaurants. Moreover, providing policy mixes such as tax on single-use packaging and the introduction of quotas whereby a certain percentage of their product sale comes for reusable packaging are seen as essential mitigation strategies.

Publication IV contributes to sustainability transition literature by highlighting how policy not only drives systemic change but also creates significant tensions across stakeholder groups that must be understood and addressed (Jørgensen, 2012; Markard et al., 2012). It emphasizes the need for policy clarity, coordinated education campaigns, financial incentives, unified return infrastructure, and technological investments to mitigate these tensions. In addition, highlighting the conflicts among various actors contributes to addressing the call for strengthening the MLP framework with perspectives at the actor level (Avelino and Wittmayer, 2016). The integration of CSR (Hahn et al., 2015) and MLP perspectives (Geels, 2002) helps reveal the interplay between institutional structures and actor-level experiences, illustrating that successful sustainability transitions require more than regulation: they demand cohesive multi-actor engagement and adaptive system design.

5 Discussion and Conclusions

The concluding chapter of this dissertation begins with a discussion about the research questions. It then explores the theoretical contributions, and the practical and policy implications of the study. Finally, the chapter highlights the primary limitations of the research and suggests directions for future investigations.

5.1 Answering the Research Questions

The overarching question that guided this dissertation is as follows: *What are the systemic tensions experienced during transitioning to sustainable packaging systems that are leading to unintended consequences, and how can they be mitigated?*

Transitions toward sustainable packaging systems are characterized by persistent tensions that arise from misalignments between new solutions and the incumbent structures, practices, and expectations that support conventional plastics. These tensions stem from cost structures, infrastructural legacies, consumer practices, regulatory frameworks, and societal narratives, and they interact in ways that reinforce one another.

A major tension stems from the economic and infrastructural dominance of conventional plastics, whose large-scale production systems, established waste management infrastructures, and accumulated expertise give them a structural advantage over emerging alternatives. Reusable, compostable, and biobased solutions must compete against this entrenched system while facing higher costs and limited infrastructural compatibility, creating tension between the goals of innovators and the realities of the current regime. Businesses and municipalities experience a further tension between the desire to adopt more sustainable solutions and the financial risk of stranding existing assets if they shift away from conventional plastics. Consumers also face a tension between long-standing expectations of low-cost packaging and the deposits, usage fees, or price premiums associated with newer options. Together, these misalignments slow adoption and reinforce dependence on the established system.

Institutional tensions emerge from the misalignment between the needs of actors developing sustainable packaging systems and the fragmented governance structures that shape their implementation. Regulatory frameworks remain largely oriented toward the recycling of fossil-based plastics, which conflicts with the expectations of municipalities, businesses, and innovators seeking clearer guidance and support for emerging systems. Ambiguities in enforcement and educational responsibilities create further tension, as policymakers, local authorities, and companies each assume that others should take the lead, leaving all actors uncertain about their roles. Infrastructure adds another layer of tension: different regions and countries maintain parallel and often incompatible systems, reflecting local priorities but clashing with the broader need for harmonization and user-friendly participation. These institutional misalignments undermine actors' confidence in

new systems and hinder consistent implementation, reinforcing a tension between the ambition to scale sustainable packaging solutions and the fragmented structures meant to govern them.

Consumer-related tensions arise from misalignments between the interests of consumers and those of system providers, policymakers, and businesses working to advance sustainable packaging. Providers and policymakers often expect consumers to adopt new routines such as returning containers or learning alternative disposal pathways, while consumers tend to prioritize convenience, clarity, and minimal disruption to their daily practices. Variations in deposit rules, return systems, and disposal requirements reflect providers' operational or regulatory needs, yet these differences conflict with consumers' preference for simple and consistent guidance. Businesses may design packaging to support durability, circularity, or logistical efficiency, but consumers may be more concerned about hygiene, product safety, and ease of use, creating further tension between system-oriented design goals and user expectations. These competing interests frequently result in confusing or discouraging user experiences, which in turn generates tension between the system's reliance on repeated consumer participation and consumers' reluctance to form new habits when the practices feel inconvenient, unclear, or risky.

Discursive tensions also shape the trajectory of sustainable packaging transitions. Public and political narratives have long positioned recyclability as the primary marker of sustainability, which conflicts with the interests of actors promoting reuse or compostability and marginalizes these approaches in policy debates. Incumbent industries reinforce this dominant narrative because it aligns with their existing infrastructures and business models, creating tension between established sector interests and the emergence of alternative solutions. As a result, new packaging options are frequently framed as inferior or impractical, generating tension between innovators' efforts to establish legitimacy and consumers' and policymakers' perception of what "sustainable packaging" should look like. These discursive misalignments undermine the credibility of alternative systems, reduce consumer trust, and weaken political willingness to introduce stronger support measures.

The unintended consequences of these tensions are significant. High costs and weak demand reinforce each other, locking eco-innovations into niche markets. Regulatory gaps and fragmented infrastructures lead to uneven enforcement and compliance, creating unfair competition and weakening the legitimacy of policies. Infrastructural incompatibility and unclear labelling result in contamination of recycling and composting streams, in some cases creating higher environmental impacts than single-use plastics. Concerns about hygiene, unclear benefits, and misleading claims give rise to both actual and perceived greenwashing, which in turn contributes to an erosion of legitimacy and consumer trust. At a systemic level, discursive lock-ins, particularly the dominance of recycling as the preferred solution, divert political attention and investment away from alternative pathways such as reuse and biodegradability. Frequent regulatory changes further increase risk aversion among businesses, discouraging innovation and slowing down market entry.

Mitigating these tensions requires an integrated approach that addresses structural, cultural, and technical dimensions simultaneously. Policy clarity and harmonization across regions are critical to reducing fragmentation and providing clear signals for investment. Financial instruments such as levies on single-use items, targeted subsidies, and calibrated deposits can help align incentives for both businesses and consumers. Infrastructure for collection, return, and treatment needs to be interoperable, standardized, and adequately resourced, with quality assurance mechanisms that build confidence in hygiene and safety. Product design improvements, supported by research and development, can enhance functionality and durability, while standardized formats can simplify logistics and reduce complexity.

Equally important are efforts to reshape consumer practices and public discourse. Large-scale education campaigns and clear, unified labelling can reduce confusion and lower the cognitive burden of participation. Normalizing reuse and alternative disposal methods requires consistent communication and opportunities for trial that encourage habit formation. Shifting the sustainability narrative beyond recyclability toward a more plural understanding of circularity will strengthen the legitimacy of new systems and counteract the influence of incumbents. Finally, innovators and smaller providers need support through coalitions, public procurement, and collaborative governance platforms that increase their visibility and capacity to shape the system.

Taken together, these measures highlight that the barriers to sustainable packaging transitions are not rooted in any single domain but in the interaction of economic, institutional, technological, behavioral, and discursive factors. The resulting tensions, if left unresolved, create reinforcing feedback that undermines environmental objectives and erodes public trust. Addressing them requires systemic coordination, where technical improvements, supportive policies, consumer engagement, and discursive shifts advance together. Only then can sustainable packaging move beyond niche initiatives and achieve meaningful, large-scale impact.

Sub-question 1: What are the sustainability challenges of sustainable packaging?

The first sub-question of this dissertation is addressed by Publication I. Taking biobased plastic packaging as an example, results are grouped into economic, environmental and social challenges.

The main economic challenge, as in other eco-innovation types, is considered to be the higher cost compared to conventional plastics. High production costs are linked not only to the materials themselves but also to the change needed to pre-existing equipment that is used for producing conventional packaging. A small market size makes large-scale investments or major redesigns of production uneconomical at present. Besides the production part itself, as these products require changes in the waste management systems, they are also found to be costly in their overall life cycle, including EOL. Moreover, long supply chains, low production yields, and uncertain competitiveness with fossil-based plastics underline the economic disadvantage of these products.

Environmental challenges related to hazardous additives, petroleum-based co-polymers, and inefficient use of energy and water raise concerns about ecotoxicity, human health risks, and resource consumption due to energy-intensive production processes. Even though these products are designed to be more sustainable than conventional plastics, their production poses sustainability issues due to inadequate advancements in their material and production technologies.

EOL poses the most pressing issues. A lack of infrastructure and issues about labelling creates challenges. For example, many bioplastics marketed as "biodegradable" only degrade in industrial composting facilities, not in home composts or natural environments, which can lead to contamination of recycling streams. PLA, the most common biodegradable plastic, if mixed with PET waste, even in small amounts, can compromise recycling quality. Inadequate disposal can also generate greenhouse gas emissions, particularly if biodegradable plastics end up in landfills. This so-called "license to litter" effect exacerbates environmental risks instead of reducing them.

Social sustainability challenges linked to biobased packaging primarily stem from the cultivation of feedstock in regions such as Asia and South America, where weak regulation and poor social standards prevail. This creates risks including poverty, exploitative labor, community displacement, and negative impacts on indigenous groups. With the expected growth of Asian markets, these issues are likely to intensify. The use of genetically modified organisms (GMOs) in biomass cultivation may trigger allergic reactions or metabolic changes, while exposure to hazardous chemicals during processing can cause skin, eye, and respiratory irritation, and in severe cases, burns or explosions.

At the consumer level, labeling practices present another challenge. Packaging often carries terms such as "compostable," "biodegradable," or "biobased," yet these labels are inconsistently used and frequently misunderstood, causing many of the associated environmental challenges. Confusion about disposal remains widespread, with many consumers discarding biobased plastics in conventional recycling bins. Moreover, consumer preferences do not always favor biobased plastics. In some cases, recycled plastics, paper, or glass are seen as more attractive alternatives.

Sub-question 2: What are the tensions experienced during the life cycle stages of sustainable packaging?

This sub-question is addressed through Publications I, II, and III by considering the different life cycle stages of sustainable packaging, including the beginning of life (BOL) (raw material and resource extraction), middle of life (MOL) (production and use), and end of life (reuse and disposal) (Kristis et al., 2003). By explicitly adopting a life cycle perspective when studying tensions, it becomes possible to observe how different tensions are connected across the various stages. This approach not only allows for the identification of the most critical challenges at each stage, but also enables prioritization of tension management strategies based on their interconnections, ensuring that efforts are targeted where they can have the greatest systemic impact.

Publications I and II reveal this interconnectedness. Based on the findings from Publications I and II, Publication III is designed to investigate how all these connect to EOL-related tensions and further investigates this interrelatedness in the EOL stage. For example, economic tensions related to raw material and resource extraction increase overall production costs, which in turn raises product prices. These higher prices create tensions in the middle-of-life stage, as consumers may be unwilling to purchase the products, keeping the market small. A limited market further exacerbates EOL challenges, as the costs of adapting infrastructure for collection, reuse, or recycling remain high. Consumers may also face difficulties in proper waste sorting in the EOL phase due to inadequate infrastructure, generating psychological and behavioral tensions that push them toward alternative sustainable packaging options. Because the market remains small and demand is limited, technological development during the production phase (MOL) is constrained, preventing improvements in product properties that would allow sustainable packaging to compete effectively with fossil-based plastics. This creates a reinforcing cycle in which high prices and limited innovation reduce consumer uptake, further constraining market growth. Similarly, a small market decreases motivation to develop proper labelling or waste management coordination efforts between regions and countries, which further confuses consumers about the EOL phase and creates further environmental issues about waste management.

Environmental problems in the BOL phase, such as land-use changes that reduce food security due to feedstock production for biobased plastic products (BBPPs), further undermine trust in these products. This generates psychological tensions for both companies and consumers, raising concerns about greenwashing and contributing to low demand. Additionally, these issues create behavioral tensions for companies, as they face increased disclosure requirements and must invest additional effort in monitoring, addressing, and communicating solutions to consumer concerns.

Sub-question 3: What kind of systemic tensions arise when a specific policy is introduced?

This sub-question is answered through Publication IV. Taking reusable packaging systems as an example, systemic tensions are categorized into economic, structural, psychological, and behavioral.

When a specific policy aimed at promoting sustainable packaging is introduced, changes in the systems are required. This can generate a range of systemic tensions that affect multiple stakeholders throughout the supply chain. New business models emerge, municipalities take on new roles for education and control of the new policy, consumers try to adapt to the changes, certain businesses make investments and change their routines, and new infrastructure needs emerge. Economically, businesses may face increased operational costs related to implementing new packaging systems, such as investments in reusable containers, cleaning, logistics, or subscription fees for service models. Consumers may encounter additional upfront costs or deposits, which can conflict with their accustomed practices of free or low-cost single-use packaging. Industry actors may

also experience misalignments in business models, where incentives for adoption are not fully aligned with actual usage or market demand.

Structurally, systemic tensions often arise from unclear responsibilities and fragmented infrastructure. Ambiguities regarding which organizations or authorities are responsible for enforcing the policy, providing guidance, or educating stakeholders can create confusion and inconsistent implementation. Fragmented systems, such as multiple providers or platforms for reusable packaging, can complicate product returns and reduce convenience for consumers. Additionally, overlapping regulations and a lack of coordination among governmental bodies can increase the complexity for businesses to comply effectively.

Psychological tensions emerge from perceptions and trust. Consumers may have concerns about hygiene, safety, or performance of the new sustainable packaging alternatives, which can reduce willingness to adopt these solutions. Symbolic or cultural meanings associated with certain packaging materials, such as negative perceptions of plastics, can further influence behavior. Uncertainty about policy stability or effectiveness can also create hesitation among businesses and consumers, slowing adoption.

Behavioral tensions are linked to habits, routines, and ease of use. Sustainable packaging often requires changes in consumer and business practices, such as returning, cleaning, or sorting products. These changes increase cognitive and practical effort, which may conflict with existing preferences for convenience. A lack of standardization in packaging design or return systems, as well as unclear instructions, can lead to improper disposal and reduce overall system efficiency. Misalignment between the expectations of consumers, businesses, and policymakers may further limit the effectiveness of the policy and hinder the transition toward more sustainable packaging systems.

Sub-question 4: How can the tensions be mitigated through different actions and strategies?

Findings from the mitigation strategies in Publications II, III, and IV are combined to answer this question and are categorized into firm-level strategies that companies are already utilizing, systemic innovations that reshape value chains and collaboration patterns, and policy interventions that stakeholders advise for scaling. The tensions experienced in the transition to sustainable packaging systems, such as balancing convenience with responsibility, cost efficiency with sustainability, global efficiency with local adaptability, and competition with collaboration can be mitigated through a combination of these strategies. Firm-level approaches address operational tensions, systemic innovations help to realign infrastructures and actor networks, and policy interventions create enabling environments that reduce fragmentation and uncertainty. Together, they form complementary levers that enable actors to anticipate, manage, and navigate systemic tensions more effectively

At the company level, firms adopt a range of strategies to manage tensions. Many small and medium-sized enterprises in the sector pursue strategies by innovating business

models, such as introducing closed-loop systems in controlled environments (airlines, conferences, cruise ships) where collection is easier to manage proper EOL, or by localizing supply chains to increase transparency and reduce transport-related environmental impacts. To optimize supply chains, innovators choose to restrict sales in regions lacking suitable EOL systems and instead establish tailored arrangements and contractual agreements to ensure proper waste management or collection/return of the products. Companies also select customers whose values align with their sustainability goals in order to enhance the credibility of their sustainability efforts, making them appear more authentic rather than opportunistic. They also join industry-relevant associations to influence standard-setting and policy through strengthened lobbying power, while simultaneously enhancing their capacity for consumer and stakeholder education, thereby increasing the legitimacy of these products. Currently, recycling dominates the discourse, limiting the legitimacy of alternatives like reuse or biodegradability. Innovators and associations aim to actively challenge these narratives by lobbying, educating policymakers, and promoting success stories. Companies also engage in niche marketing, positioning biobased or reusable products in contexts where their value is clear, gradually shifting perceptions and building legitimacy.

Moreover, collaborating with large brands is another key strategy employed, as these companies are able to scale production, drive consumer awareness, strengthen lobbying influence, and facilitate investments in end-of-life infrastructure. Such collaborations also help address systemic tensions: they mitigate the tension between market legitimacy and investment risk by validating smaller firms' innovations, reduce the tension between competition and collaboration by creating shared infrastructures, and support the resolution of convenience versus responsibility by promoting consumer uptake of reuse, recycling, or composting practices at scale. In this way, partnerships with established actors not only accelerate diffusion but also help rebalance key tensions within sustainable packaging transition. Combating greenwashing is equally important: clearer definitions, third-party certifications, and transparent communication can help avoid exaggerated claims and rebuild consumer trust. Companies engage in building ecosystems with multiple stakeholders to facilitate knowledge sharing and collaborative system development, while also offering advisory services to retailers and waste management companies in order to increase awareness and reduce concerns about sustainable products. Firms also invest heavily in innovation and research, improving product durability, functionality, barrier properties to enhance the eco-friendly appeal, consumer perception of ecological experience, and the perceived value of innovation and conducting life cycle assessments (LCA) to strengthen legitimacy and improve regulatory compliance. Utilization of certificates and ecolabels are used to reassure customers, while enhanced communication and education efforts help address greenwashing concerns and consumer knowledge gaps. Companies also pay attention to the environmental outputs through actions like using fewer chemicals. Moreover, donation of a portion of profits to environmental projects and utilizing philanthropy is used as way to combat legitimacy concerns. A third company reported making additional efforts to manage internal waste through the adoption of a more costly recycling technique.

At the policy and governance level, mitigation depends on creating a stable, coordinated, and well-supported regulatory environment. Clear, harmonized regulations reduce uncertainty, lower compliance costs, and prevent uneven enforcement across municipalities. Importantly, policies must be supported by adequate funding for enforcement and infrastructure, as vague regulations often shift responsibilities to municipalities that lack resources or expertise, creating new tensions. Policymakers can use policy mixes, combining bans, taxes, and subsidies to shape incentives. For example, bans on single-use items, taxes on unsustainable packaging, quotas about reusable and biobased packaging usage, and subsidies for technological development can collectively push the market toward sustainable alternatives. In some cases, mandating biobased packaging for specific applications (e.g., coffee capsules, beach toys) can stimulate demand and create economies of scale. At the same time, governments must avoid frequent regulatory changes, which generate uncertainty and risk aversion among producers, discouraging investment in eco-innovation. Collaborative governance models, where government, industry, NGOs, and municipalities co-create policies and coordinate responsibilities, can help align actors, avoid duplication of effort, and increase legitimacy.

Infrastructural and systemic solutions are also essential. Investments in EOL infrastructures such as unified return systems, centralized washing facilities, or reverse logistics for reusable packaging are critical to increasing convenience and ensuring that environmental benefits are realized. Standardizing product sizes, shapes, and labeling can reduce consumer confusion and contamination of waste streams, while harmonization across regions and countries reduces uncertainty for producers. Clear and consistent labeling standards, supported by nationwide education and marketing campaigns, can counter consumer skepticism and address behavioral resistance. Education campaigns should be led at the national level but also implemented locally, for example through standardized posters, unified instructions on EOL systems, and public awareness campaigns about the benefits of reuse and biobased packaging.

5.2 Contribution

5.2.1 Theoretical Implications

The key contributions of this dissertation are connected to sustainability transitions studies, eco-innovation research, the broader body of literature on "the dark side of sustainability," and critical studies on sustainable solutions.

First, it contributes to the growing body of work on the "dark side of sustainability" (e.g., Benson and Craig, 2014; Carter et al., 2020; Fuso Nerini et al., 2018; Joseph et al., 2020; Moallemi et al., 2022; Schleper, 2020; Tura et al., 2019; Zehendner et al., 2021) by adopting a critical perspective on commonly held assumptions, highlighting that sustainability efforts can produce tensions, trade-offs, and unintended consequences that are often overlooked in mainstream literature. By explicitly examining these tensions, the

study bridges insights from CSR research through utilizing the tensions definition and categorizations and theoretical frameworks with sustainability transition studies such as MLP and the lock-in concept, offering novel perspectives on how sustainability tensions manifest at different levels of the system.

Within the eco-innovation literature, there is broad recognition that the adoption of eco-innovations can drive systemic improvements across technologies, processes, and services offering benefits for both environmental sustainability and organizational performance (Gente and Pattanora, 2019). However, relatively few studies critically assess whether these innovations are truly sustainable, particularly in terms of the unintended consequences and tensions they may generate (e.g., Nawaz and Bashir, 2022). Similarly, in the sustainability transitions literature, explicit engagement with tensions remains limited (e.g., Blythe et al., 2018; Gebreselassie et al., 2025; Kainiemi et al., 2025; Markard et al., 2023; Lai and Karakaya, 2024). As a result, scholars have identified the need to more systematically explore the trade-offs and unintended outcomes that arise during sustainability-oriented transitions (Köhler et al., 2019; Susur and Karakaya, 2021).

Emerging research in ST literature has begun to address these "darker" dimensions, drawing attention to the political, social, and institutional frictions that can surface when sustainability transitions are enacted. For example, Blythe et al. (2018) critique mainstream transition narratives for reinforcing existing inequalities and concealing power imbalances. More recent studies have shown that innovation trajectories can lead to contradictory sustainability outcomes or further entrench dominant socio-technical regimes, thus curbing their transformative potential (e.g., Markard et al., 2023; Gebreselassie et al., 2025). Despite these contributions, much of this work remains fragmented and often lacks a systematic lens to understand how such tensions emerge, evolve, and are negotiated among diverse actors and institutional settings.

This research directly contributes to this growing body of work by placing tensions at the center of its analytical framework. It seeks to develop a more integrated understanding of how competing sustainability goals and interests interact in practice, and how these interactions shape the development, diffusion, and impact of eco-innovation. In doing so, the study advances both the eco-innovation and sustainability transitions literature by critically examining the socio-political and institutional complexities that underlie innovation processes. Overall, this dissertation offers a more nuanced perspective on transitions, illuminating the interplay between innovation, policy, market forces, and societal expectations. By foregrounding the tensions leading to unintended consequences inherent in sustainability efforts, it contributes to a deeper understanding of the mechanisms driving (and sometimes hindering) sustainability transitions, the role of eco-innovators within these dynamics, and the challenges that persist even in well-intentioned initiatives.

Second, the research contributes to both sustainability transitions and eco-innovation diffusion studies by combining a critical perspective with a specific focus on the EOL stage of sustainable products, highlighting how EOL phases influence both adoption and

environmental outcomes (Atlason et al., 2017; de Jesus and Mendonça, 2018; Kwok et al., 2024). While existing studies on eco-innovation diffusion and sustainability transitions frequently engage with life cycle oriented sustainability approaches (e.g., Massapina et al, 2024), they often concentrate on earlier phases of the product life cycle, such as design, production, and use. In contrast, critical research specifically addressing the EOL stage remains limited, despite its central role in determining the actual sustainability impact of innovations. By emphasizing this overlooked stage, this research not only fills a gap in the literature but also demonstrates that successful sustainability transitions require systemic consideration of the entire product life cycle, with particular attention to how EOL management shapes both market diffusion and ecological outcomes.

Third, this dissertation contributes to understanding how policy not only drives sustainability transitions but can also act as a barrier by generating tensions between different systems and actors. Within transition studies, policies are seen as key for shaping direction, for instance through tools like regulations, standards, taxation, subsidies, and innovation support (Köhler et al., 2019). In the sustainability transitions literature, much of the policy-related research has concentrated on the processes of policy design. These studies explore how aspects such as the formation of actor coalitions, agenda-setting dynamics, power relations, and agency shape transition pathways (e.g., Kern, 2011; Hess, 2014; Normann, 2015, 2017). Other strands of work pay attention to the substantive content of policies, investigating how specific objectives and design characteristics influence not only the pace but also the direction and nature of sustainability transitions. A further line of inquiry examines the governance dimension, with emphasis on the application of regulatory, economic, and informational instruments (e.g., Kivimaa and Kern, 2016; Rogge and Reichardt, 2016), as well as questions of coherence, fragmentation, and cross-sectoral or multi-level alignment of measures. However, there remains a notable gap regarding their outcomes; namely, the real-world effects, observable results, or systemic changes that policies generate (Köhler et al., 2019; Markard et al., 2016). Extending this gap further, research has not yet examined how these policy outcomes may themselves give rise to tensions. When new policies are introduced, they frequently face resistance and challenges rooted in established norms, rules, shared beliefs, and practices among different stakeholders, such as government professionals (Bakkeli, 2022), citizens or consumers (Zhang et al., 2024), and actors in the private sector, government, and production industries (Amaruzaman et al., 2023). This dissertation contributes these strands of research by examining how policy not only steers sustainability transitions but can also impede them by creating frictions between systems and actors. By focusing on the outcomes of policy interventions rather than only their design or governance, this work highlights how new regulations and instruments may generate tensions that shape trajectories in unintended ways. In doing so, the dissertation advances the discussion on policy in transition studies by foregrounding its dual role: as both a driver and a potential barrier to change.

Lastly, this dissertation contributes to the sustainable packaging literature. Research on sustainable packaging has tended to focus on narrow themes, such as material properties

(e.g., Masilamani et al., 2017), environmental impacts (e.g., De Léi et al., 2016), or consumer perceptions (e.g., Magnier and Schoormans, 2015). Such fragmented approaches overlook the systemic nature of packaging sustainability as packaging involves interconnected processes of design, production, consumption, and disposal shaped by social, cultural, institutional, and behavioral dynamics, and isolated or purely technical studies cannot adequately capture its complexity (Svanes et al., 2010). Although some methodological attempts at holistic design assessment exist (e.g., Svanes et al., 2010), empirical research that adopts a genuinely interdisciplinary and life cycle-oriented approach to sustainable packaging remains rare. The field is still dominated by disciplinary silos, whether rooted in material science, environmental assessment, or consumer studies that provide partial insights but fail to account for the broader system in which packaging operates. This narrowness risks producing solutions that appear sustainable in one dimension but create unintended consequences in others. This dissertation directly addresses this gap by advancing an empirical investigation of sustainable packaging that adopts a holistic and interdisciplinary perspective. It brings together technical, environmental, social, and institutional dimensions to provide a more comprehensive account of packaging sustainability. By critically examining how these interconnected factors shape outcomes, the dissertation moves beyond siloed approaches and contributes to building a more integrated body of empirical knowledge. In doing so, it challenges the prevailing fragmentation of the literature and offers a framework for more systemic and context-sensitive analyses of sustainable packaging.

5.2.2 **Managerial implications**

Companies can support sustainable packaging solutions through the development of new business models, such as closed-loop systems in sectors like hotels, airlines, and cruises. These models help address the systemic tension between consumer convenience and environmental responsibility. On the one hand, consumers and businesses value packaging that is easy to access, use, and dispose of with minimal effort. On the other hand, such convenience often comes at the expense of sustainability, reinforcing throwaway cultures and high levels of waste. Closed-loop systems strike a balance by maintaining convenience for the user by making the return of reusable items simple and accessible, for example, while ensuring that packaging flows remain under controlled collection and processing schemes. In doing so, they reduce the risk that convenience undermines environmental goals. Moreover, closed-loop contexts can eliminate tensions linked to broader infrastructure development: instead of requiring extensive public investments in waste collection, sorting, and recycling facilities, businesses can manage collection and recovery within their own systems, thereby reducing dependency on fragmented or underdeveloped infrastructures. These models offer advantages for both biobased plastic and reusable packaging products by allowing better control over EOL management of biobased plastics and ensuring the convenient return of reusable packaging.

Localization strategies for producer companies further strengthen sustainability performance by tackling the tensions between global supply chain efficiency and local

adaptability. For biobased packaging, sourcing raw materials locally not only lowers emissions associated with long-distance transport but also supports regional agricultural economies and ensures fresher, more controlled feedstock quality. In the case of reusable packaging, local production and distribution networks facilitate easier collection, cleaning, and redistribution of packaging units, increasing the efficiency of closed-loop systems and reducing the environmental footprint associated with logistics. Overall, localization strengthens both environmental and operational performance, making sustainable packaging more practical and scalable within specific regions.

Optimizing internal processes and supply chains is also critical for improving overall sustainability performance. For biobased packaging, this can involve streamlining raw material sourcing, reducing energy and water use in production, and minimizing chemical inputs. In the case of reusable packaging, efficient logistics for collection, cleaning, and redistribution are essential to maximize the number of reuse cycles and reduce the overall environmental footprint. Across both types of packaging, coordinated supply chain management helps lower costs, improve operational efficiency, and ensure that sustainability goals are consistently met throughout the life cycle of the product.

Managing external influences, such as market conditions, infrastructure, and broader ecosystem factors requires proactive lobbying efforts by the producer companies. For biobased packaging, this can include advocating for policies that support the use of renewable feedstocks, incentivize sustainable agricultural practices, or facilitate recycling infrastructure for bio-based plastics. In the case of reusable packaging, lobbying may focus on promoting regulations that enable return systems, standardize refillable formats, or support investment in cleaning and redistribution facilities. Companies can strengthen their impact by joining industry associations and partnering with NGOs, which not only amplifies their lobbying power but also contributes to the development of sector-wide standards, encourages knowledge sharing, and ultimately shapes the future trajectory of sustainable packaging.

To prevent potential tensions, conducting LCAs, carbon footprint analyses, and other sustainability evaluations is essential, ensuring that the environmental benefits of these products are robust and measurable. These assessments address the tension between intended environmental benefits and actual outcomes. By verifying whether packaging solutions genuinely reduce emissions, resource use, or waste, they ensure that sustainability goals are not only aspirational but also evidence-based. At the same time, transparent and rigorous evaluations decrease the risk of greenwashing by providing credible proof of environmental performance, thereby protecting companies from reputational harm and strengthening consumer and stakeholder trust. For biobased packaging, such assessments help verify that sourcing, production, and disposal processes genuinely reduce greenhouse gas emissions and resource use compared to conventional plastics. In the case of reusable packaging, life cycle evaluations can identify the optimal number of reuse cycles needed to achieve environmental advantages and highlight areas where energy or water use during cleaning and redistribution can be minimized. Overall, these evaluations provide evidence-based guidance for design, policy, and business

decisions, reducing unintended negative consequences and supporting credible sustainability claims.

Companies should also focus on technological development, as sustainable packaging must compete with incumbent products in terms of functionality and performance. This addresses the systemic tension between innovative sustainability solutions and entrenched performance standards and consumer needs for high quality products. For biobased packaging, advances in material formulation and processing are needed to ensure durability, barrier properties, and compatibility with existing production lines, while minimizing environmental impacts. In the case of reusable packaging, innovations in design, materials, and cleaning technologies are essential for increasing the number of reuse cycles, maintaining product safety, and reducing operational costs. Continuous technological improvements enable these sustainable alternatives to match or exceed conventional packaging standards, thereby facilitating market adoption and long-term viability.

Collaborating with large, established companies can increase legitimacy, facilitate market expansion, lower costs over time, and reduce investment risks. For biobased packaging, partnerships with major brands can help validate the environmental benefits of the materials, integrate them into existing supply chains, and encourage wider adoption across industries. In the case of reusable packaging, working with well-known companies can support the development of efficient collection and return systems, enhance consumer trust, and accelerate scaling, ultimately improving both economic and environmental outcomes.

Selecting customers whose values align with the company's sustainability goals is another key strategy, as it ensures that both biobased and reusable packaging solutions are adopted by users who are more likely to follow proper disposal or return practices and helps mitigate the tension between innovative packaging solutions and entrenched consumer practices. Additionally, consumer education and broad marketing campaigns play a crucial role in raising awareness about the environmental benefits of these packaging types, guiding correct usage, and encouraging behavioral changes that maximize their sustainability potential. For example, educating consumers on how to return or reuse packaging can significantly improve the efficiency of closed-loop systems, while marketing initiatives can build trust and increase acceptance of innovative, eco-innovation products.

5.2.3 **Policy Implications**

Regulations are a central driver in the shift toward sustainable packaging solutions, but they need to be designed and implemented with great care. Well-crafted rules can accelerate innovation and adoption by creating predictable conditions for investment, providing clarity for producers and consumers, fostering collaboration across sectors and stakeholders, driving infrastructure development, sending strong signals to the market about the direction of change, and creating long term cultural shifts about consumption

(Javed et al., 2024). On the other hand, unclear, inconsistent, frequently changing regulations or lack of supportive policy mix, such as subsidies, bans, or targeted taxation, can amplify existing tensions in the system and even create new ones.

The creation of clear, stable, and coordinated policies is essential. If regulations are vague in the sense of responsibilities from the start, responsibilities for implementation often fall to municipalities, which may not have sufficient resources or the capacity to handle them, creating further tensions at the local level. This can lead to uneven implementation across regions, undermining the overall effectiveness of the regulation and weakening trust in the policy process. Providing municipalities with clear guidelines alongside sufficient funding for policy enforcement would help mitigate these challenges. Vague policies also create problems for businesses, as they generate uncertainty about compliance requirements. Without clear guidance, companies may adopt different interpretations of the rules, leading to fragmented practices across the industry and, in some cases, competitive disadvantages for firms that commit resources to stricter interpretations. Moreover, when policies are unclear, companies must invest additional time and resources to interpret the requirements, which not only creates inefficiencies but can also reduce their willingness to comply.

Similarly, if regulations are developed without adequate consultation or expertise, they risk overlooking practical constraints faced by businesses or ignoring system-wide impacts such as unintended shifts in consumer behavior, and increased costs for municipalities tasked with waste management. This reflects a persistent knowledge gap among policymakers, which can be reduced through better access to consultancy and stakeholder input during the policy design stage.

Policy coordination is another critical requirement. Regulations adopted at one level of governance, whether municipal, regional, national, or EU-wide, can sometimes undermine or even contradict rules at another level, leading to inefficiencies and confusion (Abbott and Snidal, 2021; Mahtre et al., 2021). This lack of alignment is particularly problematic in the sustainable packaging sector, where products and waste streams often cross borders. Producers are left uncertain about which country's regulations apply to their products. As sustainable packaging products are relatively new, labelling practices remain unclear and lack unification, which creates significant confusion for consumers. Many find it difficult to distinguish between recyclable, compostable, or reusable options, leading to incorrect disposal and undermining the intended environmental benefits. The absence of unified systems and labelling standards not only creates confusion but also undermines trust and slows the adoption of sustainable packaging. When labels are unclear or inconsistent, consumers often do not know how to properly dispose of or reuse packaging, which can lead to frustration and mistrust in the product and the companies producing it. Clear and harmonized systems across markets would provide predictability for producers and clarity for consumers, reducing unnecessary tensions in the transition process.

In addition to clarity and coordination, policy stability is crucial. Frequent regulatory changes generate uncertainty for companies and increase the risks of investing in sustainable packaging solutions. This is particularly problematic for smaller firms, which dominate the sustainable packaging sector and often operate with limited financial resources. Sudden policy shifts can make their business models irrelevant, creating psychological tensions and deterring new market entrants. By contrast, stable and predictable regulations can help businesses plan long-term investments and innovate with confidence.

Even when regulations are well-designed, they are rarely sufficient on their own. A mix of complementary policy instruments is needed to support a systemic transition. Taxes, bans, and subsidies can play an important role in this mix. For instance, taxes and bans on certain single-use packaging items can create financial incentives for producers to move toward more sustainable options. Moreover, making certain products mandatory to be sustainable; for example, requiring biobased packaging for items such as coffee and tea capsules or beach toys, which are often mixed with biowaste or end up in the ocean, would help ensure the most environmentally beneficial EOL treatment for these products. At the same time, such mandates would increase market demand by creating a guaranteed need for sustainable alternatives. Moreover, subsidies can provide smaller firms with the financial support necessary to develop new technologies and compete with the established conventional plastics industry (Clark et al., 2018; Zhao et al., 2024).

Infrastructure development also plays a decisive role in the effectiveness of regulatory measures. Even if sustainable packaging solutions are introduced, they cannot achieve their intended impact without the necessary systems for collection and processing. This is where regulatory clarity, stable investment conditions, and financial support mechanisms intersect. By fostering infrastructure development alongside product-specific regulations, policymakers can ensure that sustainable packaging solutions are not only adopted but are also properly managed throughout their life cycle.

Taken together, these points illustrate that regulation in sustainable packaging is not simply about mandating new materials or banning harmful ones. It requires a careful balance between ambition and feasibility, between stability and adaptability, and between national interests and international coordination.

5.2.4 Limitations and Future Research Directions

This study presents examples from a specific point in time, offering a time-bound snapshot rather than a longitudinal account. As society, technology, infrastructure, and policy are likely to change, new tensions are likely to arise and some will likely resolve over time. Hence, it is beneficial to conduct other studies to examine new tension and paradox dynamics in the future. Furthermore, studies taking historical views of the development of different elements and their effects on sustainability transitions in the context of sustainable packaging need to be conducted (longitudinal studies as well as comparison of situations in different decades, etc.).

This study explores the initial steps in understanding how tensions, trade-offs, and system-level lock-ins are interconnected within the transition to sustainable packaging. It provides preliminary insights into how challenges at different levels such as regulatory, infrastructural, and market-related tensions interact and, in some cases, reinforce one another. These interactions are critical because unresolved tensions can accumulate into systemic lock-ins that slow down or even block sustainability transitions. However, more detailed research is needed to examine these interconnections comprehensively. Such research could clarify the underlying mechanisms that drive tensions, reveal how different types of tensions reinforce or counterbalance each other, and identify leverage points where interventions are most effective. In doing so, it would help to prioritize strategies for mitigating conflicts, prevent unintended consequences, and accelerate the adoption of sustainable packaging solutions.

This study examines the identified tensions qualitatively, providing in-depth insights into stakeholders' perceptions, experiences, and contextual dynamics. However, conducting complementary quantitative research would enhance the robustness and generalizability of the findings. For instance, survey-based studies could be used to assess the prevalence and intensity of specific tensions across a broader population of stakeholders, such as how widespread cost-related barriers are among small restaurants adopting reusable packaging, or how strongly consumers perceive the trade-off between convenience and environmental responsibility in takeaway services. Additionally, statistical analyses such as regression models could help identify correlations between organizational characteristics and their approaches to managing sustainability-related tensions. For instance, analyses could examine whether company size, sector (e.g., gastronomy vs. retail), or geographic location influences the adoption of closed-loop business models, or whether firms with stronger sustainability commitments are more likely to invest in local sourcing and reuse systems.

Two cases—biobased plastic packaging and reusable packaging—are used for generalization purposes. Further sustainable packaging solutions such as glass and paper packaging and newer solutions such as smart packaging need to be explored in order to provide a more comprehensive understanding of sustainable packaging transitions, and comparative studies between different packaging types need to be conducted in order to illuminate context-specific advantages, life cycle impacts, and stakeholder acceptance levels across diverse sectors.

Even though perspectives from NGOs, academia, and municipalities are included in this thesis, conducting more focused research that isolates and deeply explores the viewpoints of specific actor groups would be particularly beneficial. Such targeted analysis can provide more nuanced insights into the unique challenges faced by each actor, as well as their specific capacities, constraints, and forms of agency in addressing sustainability transitions. This is especially relevant in the context of transitions research, where scholars increasingly highlight a gap in understanding the dynamics of agency, who is able to act, how they act, and under what conditions their actions lead to systemic change. Moreover, the role of intermediary actors such as consultants, innovation hubs, industry

associations, and boundary organizations has received growing attention, yet remains underexplored. These actors often operate at the intersection of sectors, facilitating knowledge exchange, building coalitions, and translating between the goals of policymakers, businesses, and civil society. Despite their critical role in enabling, shaping, or even accelerating transitions, their agency is often overlooked in empirical studies. Addressing this gap would enrich our understanding of how systemic change unfolds, not just through dominant players but also through those who mediate, support, and steer innovation processes across multiple levels. Incorporating these deeper investigations would not only contribute to theoretical advancement but also offer practical implications for designing more effective transition governance strategies, especially in multi-stakeholder environments.

As discussed in this thesis, eco-innovation, green innovation, sustainable innovation, sustainability-oriented innovation, and environmental innovation terms are used interchangeably. Besides these terms, there are also emerging similar ones, such as clean innovation/clean tech innovation, low carbon innovation, climate innovation and green technological innovation. Even though there are some studies trying to clarify these concepts, there is still no consensus on what these terms mean and how exactly they differentiate. Further studies on conceptualization and differentiation would benefit the literature streams dealing with innovation studies related to sustainability.

Lastly, this dissertation calls for more research on sustainable packaging business models. Sustainable business model innovations and the creation of new business models that support the sustainability transitions for sustainable packaging are emerging and are also highlighted in mitigation strategies for tensions. Future research could contribute by examining these business models in greater detail, for instance through the development of typologies, classifications, and frameworks that clarify their characteristics and boundaries. Such work would help to identify which types of business models are best suited to mitigate particular systemic tensions; for example, closed-loop models for balancing convenience and responsibility, or localized models for resolving global versus local trade-offs. By providing clearer conceptual tools, this research would reduce ambiguity, prevent mismatches between business models and their contexts, and ultimately help actors navigate tensions more effectively. Moreover, further conceptual work is needed to refine and distinguish relevant terms, such as green business models, circular business models, responsible business models, and sustainability-oriented business models, which are often used interchangeably but may differ in focus, scope, and theoretical grounding. Such work would not only advance academic debate but also provide practical guidance for businesses and policymakers seeking to implement scalable and effective models for sustainable packaging within broader sustainability transitions.

References

Abbott, K.W. and Snidal, D. (2021). The governance triangle: regulatory standards institutions and the shadow of the state. In: R. Collins, ed. *The spectrum of international institutions*. Abingdon: Routledge, pp. 52–91.

Adamides, E.D., Papachristos, G. and Pomonis, N. (2012). Critical realism in supply chain research: understanding the dynamics of a seasonal goods supply chain. *International Journal of Physical Distribution & Logistics Management*, 42(10), pp. 906–930.

Arlbjørn, J.S. and Halldørsson, A. (2002). Logistics knowledge creation: reflections on content, context and processes, *International Journal of Physical Distribution & Logistics Management*, 32(1), pp. 22–40.

Aldieri, L. and Vinci, C.P. (2021). Eco-innovation in support of Sustainable Development Goals. In: W. Leal Filho, A.M. Azul, L. Brandli, A. Lange Salvia and T. Wall, eds. *Industry, Innovation and Infrastructure. Encyclopedia of the UN Sustainable Development Goals*. Cham: Springer.

Alvesson, M., and Kärreman, D., 2007. Constructing mystery: Empirical matters in theory development. *Academy of Management Review*, *32*(4), pp. 1265–1281.

Ampe, K., Paredis, E., Asveld, L., Osseweijer, P. and Block, T. (2020). A transition in the Dutch wastewater system? The struggle between discourses and with lock-ins. *Journal of Environmental Policy & Planning*, 22(2), pp. 155–169.

Amaruzaman, S., Bardsley, D. K. and Stringer, R. (2023). Analysing agricultural policy outcomes in the uplands of Indonesia: A multi-dimensional sustainability assessment. *Sustainable Development*, 31, pp. 1937–1950.

Andreewsky, E. and Bourcier, D. (2000). Abduction in language interpretation and law making, *Kybernetes*, 29(7/8), pp. 836–45.

Arthur, W.B. (1994). *Increasing returns and path dependence in the economy*. Ann Arbor: University of Michigan Press.

Atlason, R. S., Giacalone, D. and Parajuly, K. (2017). Product design in the circular economy: Users' perception of end-of-life scenarios for electrical and electronic appliances. *Journal of Cleaner Production*, 168, pp. 1059–1069.

Avelino, F. and Wittmayer, J. (2016). Shifting power relations in sustainability transitions: a multi-actor perspective. *Journal of Environmental Policy & Planning*, 18(5), pp. 628–649.

Bansal, P. (2003). From issues to actions: the importance of individual concerns and organizational values in responding to natural environmental issues. *Organization Science*, 14(5), pp. 510–527.

Bansal, P. and Song, H.C. (2017). Similar but not the same: Differentiating corporate sustainability from corporate responsibility. *Academy of Management Annals*, 11(1), pp. 105–149.

Baraldi, E., Gregori, G.L. and Perna, A. (2011). Network evolution and the embedding of complex technical solutions: The case of the Leaf House network. *Industrial Marketing Management*, 40(6), pp. 838–852.

Bakkeli, V. (2022). Handling Tensions in Frontline Policy Implementation: Legitimating, Interpreting, and Shielding a Disruptive Intervention. *International Journal of Public Administration*, 46(9), pp. 625–635.

Benson, M.H. and Craig, R.K. (2014). The end of sustainability. *Society & Natural Resources*, 27(7), pp. 777–782

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. *Research Policy*, 37, pp. 407–429.

Bessant, J. and Tidd, J. (2007). *Innovation and entrepreneurship*. Chichester: John Wiley & Sons.

Beswick-Parsons, R., Jackson, P. and Evans, D.M. (2023). Understanding national variations in reusable packaging: Commercial drivers, regulatory factors, and provisioning systems. *Geoforum*, 145, 103844.

Bhaskar, R. (2014). *The possibility of naturalism: a philosophical critique of the contemporary human sciences*. London, UK: Routledge.

Bhatti, S.H., Rashid, M., Arslan, A., Tarba, S. and Liu, Y. (2023). Servitized SMEs' performance and the influences of sustainable procurement, packaging, and distribution: The mediating role of eco-innovation. *Technovation*, 127, 102831.

Blythe, J., Silver, J., Evans, L., Armitage, D., Bennett, N. J., Moore, M.-L., Morrison, T. H. and Brown, K. (2018). The Dark Side of Transformation: Latent Risks in Contemporary Sustainability Discourse. *Antipode*, 50(5), pp. 1206–1223.

Booth, A., Sutton, A. and Papaioannou, D. (2016). *Systematic Approaches to a Successful Literature Review*. 2nd ed. London: SAGE Publications.

Brix-Asala, C., Geisbüsch, A.K., Sauer, P.C., Schöpflin, P. and Zehendner, A. (2018). Sustainability tensions in supply chains: a case study of paradoxes and their management. *Sustainability*, 10(2), pp. 424.

Bryman, A. (2016). Social Research Methods (5th ed.). London: Oxford University Press.

Burton, B.K. and Goldsby, M. (2009). Corporate social responsibility orientation, goals, and behavior: a study of small business owners. *Business and Society*, 48(1), pp. 88–104.

Byggeth, S. and Hochschorner, E. (2006). Handling trade-offs in ecodesign tools for sustainable product development and procurement. *Journal of Cleaner Production*, 14(15–16), pp. 1420–1430.

Carrillo-Hermosilla, J., Del Río, P. and Könnölä, T. (2010). Diversity of eco-innovations: reflections from selected case studies. *Journal of Cleaner Production*, 18, 1073e1083.

Carter, C.R., Kaufmann, L. and Ketchen, D.J. (2020). Expect the unexpected: toward a theory of the unintended consequences of sustainable supply chain management. *International Journal of Operations & Production Management*, 40(12), pp. 1857–1871.

Cecere, G., Corrocher, N., Gossart, C. and Ozman, M. (2014). Lock-in and path dependence: An evolutionary approach to eco-innovations. *Journal of Evolutionary Economics*, 24(5), pp. 1037–1065.

Chen, X., Yi, N., Zhang, L. and Li, D. (2018). Does institutional pressure foster corporate green innovation? Evidence from China's top 100 companies, *Journal of Cleaner Production*, 188, pp. 304–311.

Cimpan, C., Iacovidou, E., Rigamonti, L. and Thoden van Velzen, E. U. (2023). Keep circularity meaningful, inclusive and practical: A view into the plastics value chain. *Waste Management*, 166, pp. 115–121.

Clark, R., Reed, J. and Sunderland, T. (2018). Bridging funding gaps for climate and sustainable development: pitfalls, progress and potential of private finance. *Land Use Policy*, 71, pp. 335–346.

Clausen, J. and Fichter, K. (2019). The diffusion of environmental product and service innovations: Driving and inhibiting factors. *Environmental Innovation and Societal Transitions*, 31, pp. 64–95.

Coelho, P. M., Corona, B., ten Klooster, R. and Worrell, E. (2020). Sustainability of reusable packaging – Current situation and trends. *Resources, Conservation & Recycling: X*, 6, 100037.

Creswell, J.W. (2006). *Qualitative inquiry and research design: Choosing among five approaches*. 2nd ed. Thousand Oaks, CA: Sage Publications.

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 4th ed. Thousand Oaks, CA: Sage Publications.

Danermark, B. (2001). *Explaining Society: An Introduction to Critical Realism in the Social Sciences*, Florence, KY: Routledge.

David, P. A. (1985). Clio and the Economics of QWERTY. *The American Economic Review*, 75(2), pp. 332–337.

de Jesus, A. and Mendonça, S. (2018). Lost in transition? Drivers and barriers in the eco-innovation road to the circular economy. *Ecological Economics*, 145, pp. 75–89.

De Léis, C.M., Nogueira, A.R., Luiz, K., Tadini, C.C. (2016). Environmental and energy analysis of biopolymer film based on cassava starch in Brazil, *Journal of Cleaner Production*, 143, pp. 76–85.

del Río, P., Peñasco, C. and Romero-Jordán, D. (2016). What drives eco-innovators? A critical review of the empirical literature based on econometric methods. *Journal of Cleaner Production*, 112(4), pp. 2158–2170.

Denzin, N.K. and Lincoln, Y.S. (2011). *The SAGE handbook of qualitative research*. 4th ed. Thousand Oaks: Sage.

Díaz-García, C., González-Moreno, Á. and Sáez-Martínez, F.J. (2015). Eco-innovation: insights from a literature review. *Innovation: Organization & Management*, 17(1), pp. 6–23.

Diaz-Rainey, I. and Ashton, J. (2015). Investment inefficiency and the adoption of eco-innovations: the case of household energy efficiency technologies. *Energy Policy*, 82, pp. 105-117.

Dorn, M. and Stöckli, S. (2018). Social influence fosters the use of a reusable takeaway box. *Waste Management*, 79, pp. 296–301.

Duan, Y., Zhang, L., Su, H., Yang, D. and Xu, J. (2024). Eco-Innovation: Corn Stover as the Biomaterial in Packaging Designs. *Sustainability*, 16(4), Article 1381.

Dubois, A. and Gadde, L.-E. (2002). Systematic combining: An abductive approach to case research. *Journal of Business Research, 55*(7), pp. 553–560.

Eisenhardt, K.M. (1989). Building theories from case study research. *Academy of Management Review*, 14(4), pp. 532–550.

Eitan, A. and Hekkert, M.P. (2023). Locked in transition? Towards a conceptualization of path-dependence lock-ins in the renewable energy landscape. *Energy Research & Social Science*, 106, 103316.

Elder-Vass, D. (2022). Pragmatism, critical realism and the study of value. *Journal of Critical Realism*, 21(2), pp. 109–127.

European Parliament and Council (2024) *Regulation (EU) .../2024 of the European Parliament and of the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC*. Official Journal of the European Union. Available at: https://eur-lex.europa.eu (Accessed: 5 August 2025).

Fahimnia, B., Sarkis, J. and Davarzani, H. (2015). Green supply chain management: A review and bibliometric analysis. *International Journal of Production Economics*, 162, pp. 101–114.

Fernández, S., Torrecillas, C. and Labra, R.E. (2021). Drivers of eco-innovation in developing countries: the case of Chilean firms. *Technological Forecasting and Social Change*, 170, 120902.

Ferraro, G., Passaro, R., Quinto, I. and Thomas, A. (2025). The process supporting the emergence of the environmental innovation capabilities within small businesses: An empirical investigation. *Business Strategy and the Environment*, 34(1), pp. 1027–1042.

Forbes, D.P. and Kirsch, D.A. (2011). The study of emerging industries: recognizing and responding to some central problems. *Journal of Business Venturing*, 26(5), pp. 589–602.

Foxon, T. J. (2014). Technological lock-in and the role of Innovation. In: Atkinson, G., Dietz, S., Neumayer, E., and Agarwala, M., eds, *Handbook of Sustainable Development.* https://doi.org/10.4337/9781782544708.00031

Fuso Nerini, F., Tomei, J., To, L. S., Bisaga, I., Parikh, P., Black, M., Borrion, A., Spataru, C., Castán Broto, V., Anandarajah, G., Milligan, B. and Mulugetta, Y. (2018). Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nature Energy*, 3, pp. 10–15.

Galati, F., Bigliardi, B., Galati, R. and Petroni, G. (2021). Managing structural inter-organizational tensions in complex product systems projects: lessons from the Metis case. *Journal of Business Research*, 129, pp. 723–735.

Gebreselassie, S. A., Vanlauwe, B., Tesfaye, A., Paulos, Z. and Maass, B. L. (2025). Tradeoffs and synergies in food system transition: case of the Ethiopian dairy sector. *Food Security*, 17, pp. 767–780.

Geels, F.W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8–9), pp. 1257–1274.

Geels, F.W. (2004). From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. *Research Policy*, 33(6-7), pp. 897–920.

Geels, F.W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, 1(1), pp. 24–40.

Geels, F. W. (2014). Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. *Theory, Culture & Society: explorations in critical social science,* 31(5), pp. 21-40.

Geels, F.W. (2019). Socio-technical transitions to sustainability: A review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability*, 39, pp. 187–201.

Gente, V. and Pattanaro, G. (2019). The place of eco-innovation in the current sustainability debate. *Waste Management*, 88, pp. 96–101.

Gerassimidou, S., Lovat, E., Ebner, N., You, W., Hiakoumis, T., Martin, O.V. and Iacovidou, E. (2021). Development of an integrated sustainability matrix to depict challenges and trade-offs of introducing bio-based plastics in the food packaging value chain. *Journal of Cleaner Production*, 286.

German Federal Ministry of Justice (2023). *Gesetz über das Inverkehrbringen, die Rücknahme und die hochwertige Verwertung von Verpackungen (Verpackungsgesetz – VerpackG)*. [online] Available at: https://www.gesetze-im-internet.de/verpackg/ [Accessed 1 August 2025]

Graetz, F. and Smith, A. C. T. (2009). Duality Theory and Organizing Forms in Change Management. *Journal of Change Management,* 9(1), pp. 9-25.

Grin, J., Rotmans, J. and Schot, J.W. (eds.) (2010). *Transitions to Sustainable Development: New Directions in the Study of Long-Term Transformative Change*. New York: Routledge. (Routledge Studies in Sustainability Transitions).

Guba, E.G. and Lincoln, Y.S. (1994). Competing paradigms in qualitative research. In: Denzin, N.K. and Lincoln, Y.S., eds, *Handbook of Qualitative Research*, pp. 105–117. Thousand Oaks, USA: Sage Publications, Inc.

Haaja, E. and Harikkala-Laihinen, R. (2025). Emotions in sustainability advancement: Multiactor experiences of the ongoing green transition. *Journal of Cleaner Production,* 486.

Hahn, T., Figge, F., Pinkse, J. and Preuss, L. (2010). Trade-offs in corporate sustainability: You can't have your cake and eat it. *Business Strategy and the Environment,* 19(4), pp. 217-229.

Hahn, T., Pinkse, J., Preuss, L. and Figge, F. (2015). Tensions in corporate sustainability: Towards an integrative framework. *Journal of Business Ethics*, 127(2), pp. 297–316.

Hahn, T., Pinkse, J., Preuss, L. and Figge, F. (2016). Ambidexterity for corporate social performance. *Organization Studies*, 37(2), pp. 213–235.

Hahn, T., Figge, F., Pinkse, J. and Preuss, L. (2018). A paradox perspective on corporate sustainability: Descriptive, instrumental, and normative aspects. *Journal of Business Ethics*, 148(2), pp. 235–248.

Hardin, G. (1968). The Tragedy of the Commons, *Science*, 162(3859), pp. 1243–1248

Hart, C. (2018). *Doing a Literature Review: Releasing the Research Imagination*. 2nd ed. London: SAGE Publications.

Hazarika, N. and Zhang, X. (2019). Evolving theories of eco-innovation: A systematic review. *Sustainable Production and Consumption*, 19, pp. 64–78.

Healy, M. and Perry, C. (2000). Comprehensive criteria to judge validity and reliability of qualitative research within the realism paradigm. *Qualitative Market Research: An International Journal*, 3(3), pp. 118–126.

Hekkert, M., Suurs, R.A.A., Negro, S., Kuhlmann, S. and Smits, R. (2007). Functions of innovation systems: a new approach for analysing technological change. *Technological Forecasting and Social Change*, 74, pp. 413–432

Hemingway, C. and Maclagan, P. (2004). Managers' personal values as drivers of corporate social responsibility. *Journal of Business Ethics,* 50(1), pp. 33–44.

Henriques, I. and Sadorsky, P. (2007). Environmental technical and administrative innovations in the Canadian manufacturing industry. *Business Strategy and the Environment*, 16, pp. 119–132

Hermann, R. and Wigger, K. (2017). Eco-innovation drivers in value-creating networks: A case study of ship retrofitting services. *Sustainability*, 9(5), pp. 733.

Hess, David J. (2014). Sustainability transitions. A political coalition perspective. *Resources Policy*, 43 (2), pp. 278–283.

Hizarci-Payne, A.K., İpek, İ. and Kurt Gümüş, G. (2021). How environmental innovation influences firm performance: A meta-analytic review. *Business Strategy and the Environment*, 30(3), pp. 1174–1190.

Hojnik, J. and Ruzzier, M. (2016). What drives eco-innovation? A review of an emerging literature. *Environmental Innovation and Societal Transitions*, 19, pp. 31–41.

Hojnik, J., Ruzzier, M. and Manolova, T.S. (2018). Internationalization and economic performance: The mediating role of eco-innovation. *Journal of Cleaner Production*, 171, pp. 1312–1323.

Jacobsson, S. and Johnson, A. (2000). The diffusion of renewable energy technology: an analytical framework and key issues for research. *Energy Policy*, 28, pp. 625–640.

Jansson, J. (2011). Consumer eco-innovation adoption: Assessing attitudinal factors and perceived product characteristics. *Business Strategy and the Environment*, 20(3), pp. 192–210.

Jarzabkowski, P., Lê, K.J. and Van de Ven, A.H. (2013). Responding to competing strategic demands: how organizing, belonging, and performing paradoxes coevolve, *Strategic Organization*, 11(3), pp. 245–280.

Javed, A., Rapposelli, A., Khan, F., Javed, A. and Abid, N. (2024). Do green technology innovation, environmental policy, and the transition to renewable energy matter in times of ecological crises? A step towards ecological sustainability. *Technological Forecasting and Social Change*, 207, 123638.

Joseph, J., Borland, H., Orlitzky, M. and Lindgreen, A. (2020). Seeing versus doing: how businesses manage tensions in pursuit of sustainability. *Journal of Business Ethics*, 164(2), pp. 349–370.

Jørgensen, M.B. (2012). The diverging logics of integration policy making at national and city level. *International Migration Review*, 46(1), pp. 244–278.

Kainiemi, L., Laukkanen, M. and Levänen, J. (2025). Multi-sectoral interactions in energy transition: Unveiling tensions between sustainability and justice. *Applied Energy*, 384, 125437

Karakaya, E., Hidalgo, A. and Nuur, C. (2014). Diffusion of eco-innovations: A review. *Renewable and Sustainable Energy Reviews*, 33, pp. 392–399.

Kapoor, K.K., Dwivedi, Y.K. and Williams, M.D. (2014). Examining consumer acceptance of green innovations using innovation characteristics: A conceptual approach. *International Journal of Technology Management & Sustainable Development*, 13(2), pp. 135–160.

Kemp, R., Loorbach, D. and Rotmans, J. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development. *International Journal of Sustainable Development & World Ecology*, 14(1), pp. 78–91.

Kemp, R. and Pontoglio, S. (2011). The innovation effects of environmental policy instruments – A typical case of the blind men and the elephant? *Ecological Economics*, 72, pp. 28–36.

Kemp, R., Schot, J. and Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management*, 10(2), pp. 175–195.

Kern, F. (2011). Ideas, Institutions, and Interests. Explaining Policy Divergence in Fostering 'System Innovations' towards Sustainability. *Environment and Planning C: Politics and Space*, 29 (6), pp. 1116–1134.

Keränen, O., Lehtimäki, T., Komulainen, H. and Ulkuniemi, P. (2023). Changing the market for a sustainable innovation. *Industrial Marketing Management*, 108, pp. 108–121.

Kiefer, C.P., Carrillo-Hermosilla, J., Del Río, P. and Callealta Barroso, F.J. (2017). Diversity of eco-innovations: A quantitative approach. *Journal of Cleaner Production*, 166, pp. 1494–1506

Kiefer, C.P., Del Río González, P. and Carrillo-Hermosilla, J. (2019.) Drivers and barriers of eco-innovation types for sustainable transitions: A quantitative perspective. *Business Strategy and the Environment*, 28(1), pp. 155–172.

Kivimaa, P. and Kern, F. (2016). Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions, *Research Policy*, 45(1), pp. 205–217.

Klitkou, A., Bolwig, S., Hansen, T. and Wessberg, N. (2015). The role of lock-in mechanisms in transition processes: The case of energy for Road Transport. *Environmental Innovation and Societal Transitions*, 16, pp. 22–37.

Kogg, B. and Mont, O. (2012). Environmental and social responsibility in supply chains: The practice of choice and/or inter-organisational management. *Ecological Economics*, 83, pp. 154-163.

Kotilainen, K., Aalto, P., Valta, J., Rautiainen, A., Kojo, M. and Sovacool, B. K. (2019). From path dependence to policy mixes for Nordic Electric Mobility: Lessons for Accelerating Future Transport Transitions. *Policy Sciences*, 52(4), pp. 573–600.

Köhler, J., Geels, F.W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M.S., Nykvist, B., Pel, B., Raven, R., Rohracher, H., Sandén, B., Schot, J., Sovacool, B., Turnheim, B., Welch, D. and Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions*, 31, pp. 1–32.

Kvale, S. and Brinkmann, S. (2009). *InterViews: Learning the craft of qualitative research interviewing*. 2nd ed. Thousand Oaks: Sage.

Kwok, K.H., Savaget, P., Fukushige, S. and Halog, A. (2024). The necessity for end-of-life photovoltaic technology waste management policy: A systematic review. *Journal of Cleaner Production,* 142497.

Lai, Y.Y. and Karakaya, E. (2024). Rethinking the sustainability of transitions: An illustrative case of burden-shifting and sociotechnical dynamics of aviation fuel in Sweden. *Energy Research & Social Science*, 113, 103574.

Leslie, L.M. (2019). Diversity initiative effectiveness: a typological theory of unintended consequences, *Academy of Management Review*, 44(3), pp. 538–563.

Lewis, M. (2000). Exploring paradox: Toward a more comprehensive guide. *Academy of Management Review*, 25, pp. 760–776.

López Pérez, G., García Sánchez, I.M. and Zafra Gómez, J.L. (2024). A systematic literature review and bibliometric analysis of eco-innovation on financial performance: Identifying barriers and drivers. *Business Strategy and the Environment*, 33(2), pp. 1321–1340.

Loorbach, D. (2009). Transition management for sustainable development: A prescriptive, complexity-based governance framework, *Governance*, 22(1), pp. 161–183.

Loorbach, D., Frantzeskaki, N. and Avelino, F. (2017). Sustainability Transitions Research: Transforming Science and Practice for Societal Change. *Annual Review of Environment and Resources,* 42, pp. 599-626.

Magnier, L. and Schoormans, J. (2015). Consumer reactions to sustainable packaging: The interplay of visual appearance, verbal claim and environmental concern, *Journal of Environmental Psychology*, 44, pp. 53–62.

Manzhynski, S. and Figge, F. (2020). Coopetition for sustainability: between organizational benefit and societal good, *Business Strategy and the Environment*, 29(3), pp. 827–837.

Markard, J. (2018). The next phase of the energy transition and its implications for research and policy. *Nature Energy,* 3(8), pp. 628-633.

Markard, J., Raven, R. and Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, 41(6), pp. 955-967.

Markard, J., Suter, M. and Ingold, K. (2016). Policy influence of sustainability transition research: The case of Swiss energy policy, *Environmental Innovation and Societal Transitions*, 18, pp. 215–237.

Markard, J., Wells, P., Yap, X.-S. and van Lente, H. (2023). Unsustainabilities: A study on SUVs and space tourism and a research agenda for transition studies. *Energy Research & Social Science*, 106, 103302.

Masilamani, D., Srinivasan, V., Ramachandran, R. K., Gopinath, A., Madhan, B. and Saravanan, P. (2017). Sustainable packaging materials from tannery trimming solid waste: A new paradigm in wealth from waste approaches. *Journal of Cleaner Production*, 164, pp. 885–891.

Massapina, M., Meireles, M. and Madaleno, M. (2024). Circular economy in firms' strategies—What are the determinants of eco-innovation? *Environment, Development and Sustainability*.

Maye, D., Kirwan, J. and Brunori, G. (2019). Ethics and responsibilisation in agri-food governance: the single-use plastics debate and strategies to introduce reusable coffee cups in UK retail chains, *Agriculture and Human Values*, 36(2), pp. 301–312.

Meqdadi, O., Johnsen, T.E. and Johnsen, R.E. (2017). The role of power and trust in spreading sustainability initiatives across supply networks: A case study in the bio-chemical industry. *Industrial Marketing Management*, 62, pp. 61–76.

Merton, R.K. (1936). The unanticipated consequences of purposive social action. *American Sociological Review*, 1(6), pp. 894–904.

Moallemi, E.A., Hosseini, S.H., Eker, S., Gao, L., Bertone, E., Szetey, K. and Bryan, B.A. (2022). Eight archetypes of Sustainable Development Goal (SDG) synergies and trade-offs. *Earth's Future.*

Miles, M. B. and Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook,* 2nd ed. Sage Publications, Inc.

Miles, M.B., Huberman, A.M. and Saldana, J. (2014). *Qualitative Data Analysis: A Methods Sourcebook,* 3rd ed. Los Angeles, CA: Sage Publications.

Miller, S. A., Horvath, A. and Monteiro, J. (2021). Recycled-content product policies and circular economy: Environmental and economic impacts. *Resources, Conservation and Recycling*, 170, 105585.

Molina-Besch, K. (2022). Use phase and end-of-life modeling of Biobased Biodegradable Plastics in life cycle assessment: A Review. *Clean Technologies and Environmental Policy*, 24(10), pp. 3253–3272.

Nawaz, W. and Bashir, H. (2022). Managing the unintended consequences of radical sustainability innovations: The case of catastrophic failure of leaded gasoline industry. *Journal of Cleaner Production*, 375, 134175.

Normann, H.E. (2015). The role of politics in sustainable transitions. The rise and decline of offshore wind in Norway. *Environmental Innovation and Societal Transit*ions, 15, pp. 180–193.

Normann, H.E. (2017). Policy networks in energy transitions. The cases of carbon capture and storage and offshore wind in Norway. *Technological Forecasting and Societal Change*, 118, pp. 80–93.

OECD (2009). *Sustainable Manufacturing and Eco-Innovation: Framework, Practices and Measurement. Synthesis Report*. Paris: Organisation for Economic Co-operation and Development.

O'Mahoney, J. and Vincent, S. (2014). Critical realism as an empirical project: a beginner's guide. In: Edwards, P.K., O'Mahoney, J., and Vincent, S., eds. *Studying organizations using critical realism: a practical guide*. Oxford: Oxford University Press, pp. 1–20.

Paipa-Sanabria, E.G., Montoya, D.G. and Coronado Hernandez, J. (2025). Understanding eco-innovation: A critical examination of theories and tools for achieving societal sustainability. *Journal of Sustainable Research*, 7(1), e250013.

Pansera, M. (2011). The Origins and Purpose of Eco-Innovation. *Global Environment*, 7/8, pp. 128-155.

Papachristos, G., Sofianos, A. and Adamides, E. (2013). System interactions in socio-technical transitions: Extending the multi-level perspective. *Environmental Innovation and Societal Transitions*, 7, pp. 53–69.

Parker, I., Scott, S. and Geddes, A. (2019). Snowball sampling. In: Smith, J.A., ed. *Qualitative research in psychology: Expanding perspectives in methodology and design*. 3rd ed. London: Sage, pp. 193–205.

Patterson, J., Schulz, K., Vervoort, J., Van der Hel, S., Widerberg, O., Adler, C., Hurlbert, M., Anderton, K., Sethi, M. and Barau, A. (2017). Exploring the governance and politics of transformations towards sustainability. *Environmental Innovation and Societal Transitions*, 24, pp. 1–16.

Patton, M.Q. (1999). Enhancing the quality and credibility of qualitative analysis. *Health Services Research*, 34(5 Pt 2), pp. 1189–1208.

Peltola, T., Aarikka-Stenroos, L., Viana, E. and Mäkinen, S. (2016). Value capture in business ecosystems for municipal solid waste management: Comparison between two local environments. *Journal of Cleaner Production,* 137, pp. 1270–1279.

Poole, M.S. and Van de Ven, A. (1989). Using paradox to build management and organizational theory, *Academy of Management Review*, 14(4), pp. 562–578.

Porter, M.E. and van der Linde, C. ´(1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, 9(4), pp. 97–118.

Porumboiu, C. (2020). The importance of emerging industries: the case of biopharma. *In: Eurasian Economic Perspectives: Proceedings of the 28th Eurasia Business and Economics Society Conference*. Cham: Springer International Publishing, pp. 3–12.

Reichertz, J. (2010). Abduction: The logic of discovery of grounded theory. *Forum: Qualitative Social Research*, 11(1).

Rennings, K. (2000). Redefining innovation—eco-innovation research and the contribution from ecological economics. *Ecological Economics*, 32(2), pp. 319–332.

Rip, A. and Kemp, R. (1998). Technological change. In: Rayner, S. and Malone, E.L., eds., *Human Choice and Climate Change*, Volume 2. Columbus: Battelle Press, pp. 327–399.

Rocco, T. S. and Plakhotnik, M. S. (2009). Literature Reviews, Conceptual Frameworks, and Theoretical Frameworks: Terms, Functions, and Distinctions. *Human Resource Development Review*, *8*(1), pp. 120–130.

Rogers, E. M. (2003). *Diffusion of Innovations.* 5th ed. New York: Free Press.

Rogge, K.S. and Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis, *Research Policy*, 45(8), pp. 1620–1635.

Salmenperä, H., Pitkänen, K., Kautto, P. and Saikku, L. (2021). Critical factors for enhancing the circular economy in waste management. *Journal of Cleaner Production*, 280, 124339.

Sandberg, E. (2017). Introducing the paradox theory in logistics and SCM research – examples from a global sourcing context, *International Journal of Logistics Research and Applications*, 20(5), pp. 459–474.

Saunders, M.N.K., Lewis, P. and Thornhill, A. (2019). *Research methods for business students*. New York, USA: Pearson.

Schad, J., Lewis, M.W., Raisch, S. and Smith, W.K. (2016). Paradox research in management science: looking back to move forward, *Academy of Management Annals*, 10(1), pp. 5–64.

Schiederig, T., Tietze, F. and Herstatt, C. (2012). Green innovation in technology and innovation management – An exploratory literature review. *R&D Management*, 42(2), pp. 180–192.

Schleper, M.C. (2020). The hidden side of sustainable operations and supply chain management: unanticipated outcomes, trade-offs and tensions. *International Journal of Operations & Production Management*, 40(12), pp. 1881–1902.

Seshadri, S. (2013). *The sustainability syndicate: Shared responsibility in a trans-organizational business model*. *Industrial Marketing Management*, 42(5), pp. 765–772.

Seto, K.C., Davis, S.J., Mitchell, R.B., Stokes, E.C., Unruh, G. and Ürge-Vorsatz, D. (2016). Carbon lock-in: Types, causes, and policy implications. *Annual Review of Environment and Resources*, 41(1), pp. 425–452.

Simoens, M.C., Leipold, S. and Fuenfschilling, L. (2022). Locked in unsustainability: Understanding lock-ins and their interactions using the case of food packaging. *Environmental Innovation and Societal Transitions*, 45, pp. 14–29.

Slawinski, N. and Bansal, P. (2015). Short on time: intertemporal tensions in business sustainability. *Organizational Science*, 26(2), pp. 531–549.

Smith, W.K. and Lewis, M.W. (2011). Toward a theory of paradox: A dynamic equilibrium model of organizing. *Academy of Management Review*, 36(2), pp. 381–403.

Smith, A. and Stirling, A. (2010). The politics of social-ecological resilience and sustainable socio-technical transitions. *Ecology and Society*, 15(1), 11.

Smith, A., Stirling, A. and Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research Policy*, 34(10), pp. 1491–1510.

Smol, M., Kulczycka, J. and Avdiushchenko, A. (2017)**.** Circular economy indicators in relation to eco-innovation in European regions. *Clean Technologies and Environmental Policy*, 19(3), pp. 669–678.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, pp. 333–339.

Solow, R.M. (1974). The economics of resources or the resources of economics. *American Economic Review*, 64(2), pp. 1–14.

Sorrell, S. (2018). Explaining sociotechnical transitions: A critical realist perspective. *Research Policy*, 47(7), pp. 1267–1282.

Spierling, S., Röttger, C., Venkatachalam, V., Mudersbach, M., Herrmann, C. and Endres, H.J. (2018). Bio-based plastics – A review of environmental, social and economic impact assessments, *Journal of Cleaner Production*, 185, pp. 476–491.

Stebbins, R.A. (2001). *Exploratory research in the social sciences*. Thousand Oaks, CA: Sage.

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Boston: Irwin McGraw-Hill.

Stirling, A. (2008). "Opening up" and "closing down": Power, participation, and pluralism in the social appraisal of technology. *Science, Technology, & Human Values*, 33(2), pp. 262–294.

STRN (2010). A Research Agenda for the Sustainability Transitions Research Network. Available online at. STRN. https://transitionsnetwork.org/about-strn/research_agenda/

Sumrin, S., Gupta, S., Asaad, Y., Wang, Y. Bhattacharya, S. and Foroudi, P. (2021). Eco-innovation for environment and waste prevention. *Journal of Business Research*, 122, pp. 627–639.

Sustainability Transitions Research Network (STRN), 2025. *IST 2025 Conference Theme: Tensions and Trade-Offs in Structural Changes for Sustainability Transitions*. Available at: https://transitionsnetwork.org/ist-2025/conference-theme/

Susur, E. and Karakaya, E. (2021). A reflexive perspective for sustainability assumptions in transition studies. *Environmental Innovation and Societal Transitions*, 39, pp. 34–54.

Svanes, E., Vold, M., Møller, H., Pettersen, M., Larsen, H. and Hanssen, O. (2010). Sustainable packaging design: A holistic methodology for packaging design, *Packaging Technology and Science*, 23, pp. 161 - 175.

Sydow, J., Schreyögg, G. and Koch, J. (2009). Organizational path dependence: opening the black box. *Academy of Management Review*, 34(4), pp. 689–709.

Taylor, S.S., Fisher, D. and Dufresne, R.L. (2002), The aesthetics of management storytelling: a key to organizational learning, *Management Learning*., 33(3), pp. 313–330.

Tschiedel, C., Feiter, T. and Kock, A. (2024). Engaging Paradoxical Tensions in Cross-Sectoral Collaborative Business Model Development for Sustainability: A Case Study in the Urban Energy Transition. *Organization & Environment*, 38.

Theobald, K., Mich, A., Hillesheim, S., Hartard, S. and Rohn, H. (2024). One year of mandatory reusable packaging in Germany: opportunities and obstacles from the perspective of consumers and companies. *Sustainability*, 16(13).

Timmermans, S., and Tavory, I. (2012). Theory construction in qualitative research: From grounded theory to abductive analysis. *Sociological Theory, 30*(3), pp. 167–186.

Tóth, Z., Peters, L.D., Pressey, A. and Johnston, W.J. (2018). Tension in a value co-creation context: a network case study. *Industrial Marketing Management*, 70, pp. 34–45.

Tura, N., Keränen, J. and Patala, S. (2019). The darker side of sustainability: tensions from sustainable business practices in business networks. *Industrial Marketing Management*, 77, pp. 221–231.

Turkcu, D. and Tura, N. (2023). The dark side of sustainable packaging: Battling with sustainability tensions, *Sustainable Production and Consumption*, 40, pp. 412–421.

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, 28(12), pp. 817–830.

van den Broek, K.L., Negro, S.O. and Hekkert, M.P. (2024). Mapping mental models in sustainability transitions. *Environmental Innovation and Societal Transitions*, 51, 100792.

van der Byl, A. and Slawinski, N. (2015). Embracing tensions in corporate sustainability: a review of research from win-wins and trade-offs to paradoxes and beyond, *Organization and Environment*, 28, pp. 54-79.

Voulvoulis, N., Giakoumis, T., Hunt, C., Kioupi, V., Petrou, N., Souliotis, I., Vaghela, C. and binti Wan Rosely, W.I.H. (2022). Systems thinking as a paradigm shift for sustainability transformation. *Global Environmental Change*, 75, 102544.

Wang, Y., García-Herrero, I., Vanhuylenbroeck, E. and De Meulenaer, B. (2023). Reusable packaging systems in the food sector: Environmental and business trade-offs. *Journal of Cleaner Production*, 408, 137094.

Xavier, A.F., Naveiro, R.M., Aoussat, A. and Reyes, T. (2017). Systematic literature review of eco-innovation models: Opportunities and recommendations for future research. *Journal of Cleaner Production*, 149, pp. 1278–1302.

Xiao, C., Wilhelm, M., van der Vaart, T. and van Donk, D.P. (2019). Inside the buying firm: Exploring responses to paradoxical tensions in sustainable supply chain management, *Journal of Supply Chain Management*, 55(1), pp. 3–20.

Zauberman, G. (2003). The intertemporal dynamics of consumer lock-in. *Journal of Consumer Research*, 30(3), pp. 405–419.

Zehendner, A.G., Sauer, P.C., Schöpflin, P., Kähkönen, A.K. and Seuring, S. (2021). Paradoxical tensions in sustainable supply chain management: insights from the electronics multi-tier supply chain context. *International Journal of Operations & Production Management*, 41(6), pp. 882–907.

Zhang, T. (2023). Critical realism: a critical evaluation. *Social Epistemology*, 37(1), pp. 15–29.

Zhang, J., Shi, D., Ma. L., Wu, Y., Liu, S. and Li, J. (2024). The role of household energy consumption behavior in environmental policy outcomes —the case of driving restriction policy in Zhengzhou. *Energy Policy,*188.

Zhao, L., Chong, K.M., Gooi, L.M. and Yan, L. (2024). Research on the impact of government fiscal subsidies and tax incentive mechanism on the output of green patents in enterprises. *Finance Research Letters*, 61, 104997.

Publication I

Turkcu, D., Tura, N., and Ojanen, V.
A Conceptual Framework of the Sustainability Challenges Experienced during the Life Cycle of Biobased Packaging Products

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A Conceptual Framework of the Sustainability Challenges Experienced during the Life Cycle of Biobased Packaging Products

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Abstract: Biobased packaging products are framed as products that have environmental value. They are promoted by many institutions and companies as a way of addressing climate change challenges by decreasing carbon footprints and providing alternatives for the fossil fuel-based economy. The use of biobased packaging products has started to become widespread, and they are increasingly commercially available. Despite the acknowledged benefits of such products, there are several challenges associated with the use of them. This paper provides a state-of-the-art review of biobased packaging products and presents a conceptual framework of the sustainability challenges experienced over their life cycles. The framework categorizes the identified challenges by their environmental, social, and economic impact, as well in terms of the different life cycle stages, from beginning of life to middle of life to end of life. In addition to increasing the understanding of the challenges associated with biobased packaging materials and their use, the proposed framework benefits the analysis of these challenges in different organizations, the identification of potential greenwashing, and the development of mitigation strategies to overcome the challenges. Furthermore, this study reveals gaps in the literature to be considered in future research into biobased packaging products.

Keywords: biobased; packaging; biodegradable; sustainability; challenges; life cycle

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1. Introduction

Consumer lifestyles have been changed by increasing urbanization, population and economic growth, and the rising standard of living. Moreover, the demand for pre-packaged, convenient, and single-serving foodstuffs, consumer goods, and healthcare/hygiene products, as well as the rapid growth in e-commerce [1], the aging population, and long and complex supply chains [2] are all increasing the demand for packaging. According to industry analyst Smithers Packaging (2019), the global packaging market increased by 8.4% to USD 914.7 billion from 2015 to 2019 and is expected to increase by 2.8% annually to USD 1.05 trillion in 2024 [3]. COVID-19 has specifically increased packaging consumption, as it has created an increasing trend toward internet shopping and food delivery. This trend is expected to continue in the coming years. Currently, packaging is a part of everyday life. This is especially true of plastic packaging, with consumption of this product type having increased significantly [4].

At present, the packaging industry heavily relies on petroleum-based plastics [5], which have many advantages in terms of being lightweight, durable, flexible, affordable, strong, and convenient [6]. However, plastic packaging is also associated with many disadvantages and challenges related to economic, environmental, social, and technical issues [7]. The main of these disadvantages stems from the possible scarcity of fossil fuels in the future and the production processes that contribute to increased greenhouse gas emissions in the value chain. New legislations, such as the banning of single-use plastic packaging, is also creating demand for alternative types of packaging. Indeed, societal demand for sustainable production and consumption is also growing due to

increasing awareness of the problems related to oil-based plastics, such as problematic waste management, the accumulation of plastics in our seas and oceans, and the negative health impacts on humans and animals. Consequently, the amendments being made to regulations alongside the increase in public pressure are creating a demand for the development of alternatives to fossil-based plastic packaging [6].

Renewable and biobased options are being developed for packaging as a solution to the challenges associated with conventional plastics. These alternatives are claimed to have advantages compared to fossil-based options, such as smaller carbon footprint, increased acceptance by consumers, and more sustainable end-of-life (EOL) options [4]. Moreover, it is claimed that biobased products will decrease the dependency on fossil fuels and the landfill of plastic solid waste [8]. Moreover, the price of biobased products depends on biomass, which a has more stable price compared to the fluctuations in oil prices [9]. The production costs associated with biobased products are also expected to decrease in the near future, as the demand for biobased products is expected to increase, allowing economies of scale [6].

Despite the multiple benefits, there are multiple challenges associated with biobased packaging products [6,8,10]. As these products are highly promoted as a part of the bioeconomy, sustainability-related risks and challenges should be considered in a holistic way [6]. These include challenges such as possible land use change from food production to biomass production [6,8,10–19], safety and health problems in production and processing [6,8,17], issues such as toxic pesticides [6,8,11,13,15–17], and the use of genetically modified organisms (GMO) in biomass production [6,8,17,19], and challenges related to the EOL of the products, such as consumers not knowing how to separate waste [6,17,20,21], and a lack of infrastructure [21]. The current literature acknowledges that these challenges should be considered throughout the products' value chains and from the various sustainability aspects, including environmental, economic, and social concerns [6,10]. However, there is a lack of research reviewing all three of these sustainability aspects in a holistic way, especially in relation to studies with a social perspective.

This study goes beyond the state of the art in this field (e.g., Gerassimidou et al. (2021), Spierling et al. (2018) [6,10]) by explaining how different challenges can interact within different sustainability domains over different life cycle phases. In this study, the sustainability challenges of biobased packaging products are considered in a holistic way, not only considering them in comparison to conventional plastics. This is because biobased plastics may also be used as an alternative to paper, glass, recycled plastic, or some other material. By analyzing these problems based on how they contribute to different sustainability domains within different life cycle stages, this study also aims to identify the most crucial issues that may work as barriers to the realization of the more demanding sustainable development objectives.

Two research questions were formed to address these research gaps:

1. What are the main environmental, social, and economic challenges associated with biobased packaging products in their different life cycle stages?
2. What are the missing parts and emerging themes in the current literature on the sustainability of biobased packaging products?

Based on the review of the current literature, this study introduces a conceptual framework of the challenges over the life cycle of biobased packaging products. This framework analyzes and categorizes the challenges in accordance with their sustainability aspects, using the triple bottom line concept through three dimensions of: the environmental, economic, and social [22], which are commonly used to analyze the sustainability of the companies and products [23,24]. Environmental sustainability is related to the efficiency of energy use, waste management and reduction, pollution reduction, and the use of hazardous/harmful/toxic materials [23]. Social sustainability relates to how people will be affected in terms of equality, health, diversity, connectedness, quality of life, democracy, and accountable governance [25]. Economic sustainability refers to balanced long-term growth without negative impacts on the environment, society, or company culture [26]. This study

contributes to the existing research by highlighting that different challenges of biobased packaging products can interact with each other across different sustainability dimensions, which emphasizes the need to create a holistic picture of the possible challenges. The prior literature focuses mainly on the challenges from economic and environmental perspectives, but we also highlight the challenges associated with the social dimension. By discussing the challenges associated with biobased packaging materials from multiple viewpoints, this study aims to help companies using such products identify these challenges and avoid possible greenwashing activities. Furthermore, by dividing the challenges according to the life cycle stages of the products as beginning of life (BOL), middle of life (MOL), and end of life (EOL) [27], we provide a tool for companies to develop mitigation and prevention measures targeted for actions in certain life cycle stages.

2. Background Literature

2.1. Defining Biobased Packaging

Currently, the largest field of use for biobased plastics is the packaging industry [17]. Biobased packaging products are products made from corn, sugar beets, bamboo, wood, and sugarcane. The most common biobased packaging products are biobased plastic packaging products made from sugarcane [6]. Biobased plastic packaging products are plastic products made of biological resources that are (partly) derived from renewable resources or the side streams of agri-food products [28]. The biomass type used in bioplastics is often sugarcane, cellulose, lignin, and corn, and they are mainly produced in Asia (followed by Europe, North America, and South Africa) [10]. The term 'bioplastic' or 'biobased plastic' is often used loosely and synonymously alongside 'biodegradable plastic'. However, even though some bioplastics are indeed biodegradable, not all are.

Biobased materials can be made from the first, second, or third generation of feedstocks. First-generation feedstocks are feedstocks such as corn, whey, and sugarcane [6]. Second-generation feedstocks are byproducts from the agricultural and forestry industries and municipal solid waste. Third-generation feedstocks include biomass from algae [29].

There exist different categories of biobased plastics:

1. Biobased/renewable and non-biodegradable plastic (such as polyethylene (PE), polypropylene (PP), or polyethylene terephthalate (PET)); and
2. Biobased/renewable and biodegradable plastic (such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), or polybutylene succinate (PBS)).

Biodegradable and compostable plastics can be broken down by microorganisms such as bacteria called Pseudomonas and fungal species such as Rhizopus delemar, Rhizophus arrizus, Aspergillus flavus, and Penicillium [30]. With the help of these organisms, plastics are broken into water, carbon dioxide, mineral salts, and new biomass within a defined period and under certain conditions. For a product to be called biodegradable or compostable, the material must comply with official standards of biodegradability, and there are certifications that prove the compostability or biodegradability of the products [31]. The temperature, duration, presence of microorganisms, nutrients, PH, oxygen, and moisture levels all affect if and how fast the material will biodegrade [32]. When a product composts, in addition to biodegradation, it also becomes available to add nutrition to the soil [33]. Hence, a material that degrades in industrial composting does not necessarily degrade in home composting, as different materials need specific conditions to biodegrade.

The biodegradability of biobased plastics is dependent on the chemical and physical structure of the monomer rather than the source material [34]. Surface conditions such as surface area, hydrophilic and hydrophobic properties, first-order structures such as the chemical structure, molecular weight, and molecular weight distribution, and high-order structures such as glass transition temperature, melting temperature, modules of elasticity, crystallinity, and crystal structure of the polymers play roles in determining if the polymers are biodegradable or not [35].

This paper only focuses on biobased plastics, both biodegradable and non-biodegradable. Even though there are petroleum-based plastics that can be biodegradable, they are not in the scope of this paper.

Many biobased materials are not made of 100% biobased products. They are often a mix of biobased and non-biobased materials. There are national regulations stating the required threshold for the renewable content of a product to be called biobased. However, there is no universal consensus on this matter [6]. There are labels that indicate the percentage of biomass content in the biobased material provided by certifiers such as DIN CERTCO and TUV AUSTRIA Belgium [36].

2.2. Sustainability and Life Cycle Management of Biobased Packaging

The biobased product industry is developing very quickly in terms of new materials and innovations. However, much of the research is not yet public, and there are still many products that are being developed and waiting for food contact approval, for example [4]. As the development of and challenges associated with these products are still an emerging research area, their impact is not yet well known. The environmental sustainability performance of biobased plastics is especially being scrutinized by different stakeholder groups, and the amount of literature on environmental concerns has been increasing [6,10], while studies considering the economic and social aspects remain very limited. So far, no fully biobased biodegradable product exists that could meet the barrier, mechanical, and sealing performance criteria together with cost effectiveness [12,37,38]. As the biobased packaging product industry develops, the research regarding the sustainability of biobased packaging products is developing, too. So far, there is no real consensus on how to analyze and assess their sustainability [10].

Life cycle management (LCM) is an integrated approach to consider the environmental, economic, technological, social, and economic aspects of products or organizations [39]. LCM requires companies to take a sustainability-driven approach and helps companies to take responsibility for the product [40]. As LCM is seen as a useful tool to help companies assess their sustainability efforts, it is taken as a categorization approach during the creation of the framework. A product's life cycle is considered to have three main phases: beginning of life (BOL), middle of life (MOL), and end of life (EOL). The BOL phase mainly includes design and getting the raw material, MOL includes production, use, service, and maintenance, and EOL includes reuse or disposal [27]. Kiritsis' approach to categorization [27] was used when considering the life cycle stages of the products in the framework to help assess biobased packaging products' sustainability, as can be seen in Figure 1.

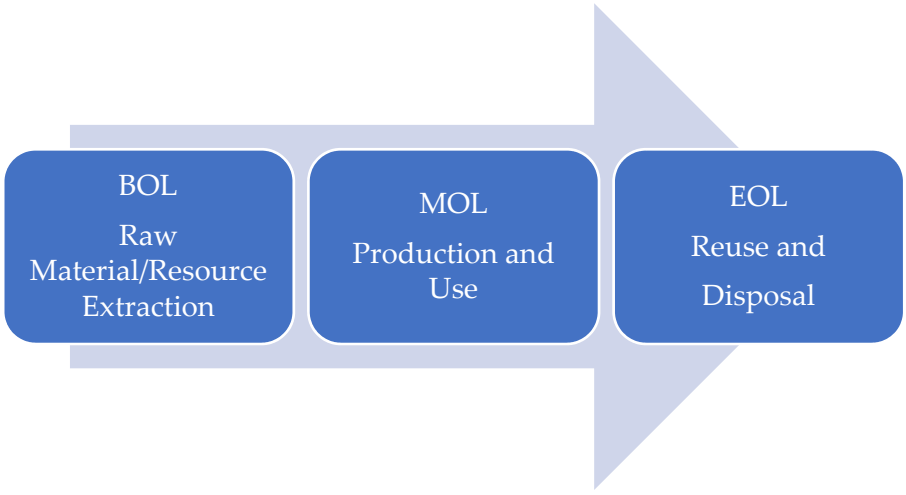

Figure 1. Product lifecycle of biobased plastics.

Most scholars in the area are analyzing biobased plastics in one or two stages of their life cycles by using life cycle assessment to point out the challenges [6]. There are

several scholars who have studied the overall life cycles of these products. There are also many studies focusing mainly on the end of life, i.e., biodegradation or recycling options. Especially when it comes to the social aspects, previous studies often focus on either only the problems related to usage [21], perception [20], the EOL options (consumers and society) [41,42], or the workers in the production stage [8]. Hence, it is very hard to obtain an overall picture of the social sustainability aspects.

Most of the papers in the literature review focus on the technical aspects of biobased packaging products. In the literature, the main technological challenges are defined as a lack of water vapor and gas barrier properties [19], being brittle, and having issues related to biodegradation [4]. As the focus of this study is to examine the challenges from the perspective of the Trible bottom line, technological issues will not be analyzed in detail.

The most thorough review of biobased plastics has been completed by Gerassimidou et al. [6]. This study points out the blind spots in the system and underlines the importance of feedstock selection, infrastructure availability, and the interactions between sustainability domains by making comparisons between biobased and conventional plastics. This study does not include second or third-generation feedstocks.

When it comes to researchers focusing on more than one stage of the life cycle or more than one sustainability aspect, there are a very limited number of studies. Spierling et al. [10] conducted a research review based on life cycle assessment (LCA), social life cycle assessment, and life cycle costing studies in order to fill the gap in quantifiable research on a holistic view that includes the socio-economic side of biobased plastics [10]. Even though this study analyzed several sustainability aspects of the products, it only focused on numerical life cycle assessments, excluding other assessment methods. Moreover, this study focused on cradle-to-gate studies, excluding the use and EOL phases. The study was conducted with the purpose of providing suggestions for regulatory bodies, not companies. Moreover, the study was conducted as a comparison between first-generation biobased products and conventional plastics. In the literature, most of the studies conducted are on first-generation feedstocks [6], while second and third-generation feedstocks [29,43] are often excluded. Moreover, many of the LCA studies are conducted with a cradle-to-gate approach, and the EOL section is excluded [31].

Álvarez-Chávez et al. [8] conducted research that qualitatively analyzed and compared the sustainability of different types of biobased plastics. They tried to analyze the products in terms of the safety and health of consumers, workers, and the environment. This study focused on providing suggestions for companies to make a calculated decision on which biobased products they should use. This study primarily focused on environmental health and safety, while less attention was paid to the economic and social aspects.

This study is conducted to fill the gap of creating a holistic framework to understand and manage biobased plastic packaging products' environmental, social and economic risks through the whole lifecycle, intended mainly for the companies to mitigate and manage their risks. The conceptual framework of challenges of biobased (plastic) packaging products is presented in the result section of this paper.

3. Methods and Descriptive Results

This study examines the overall environmental, social, and economic risks associated with biobased plastic packaging in their whole life cycle. The study explores the prior literature, comprising articles from the Scopus and Web of Science databases on bioplastics and biobased plastic packaging. These databases were selected as they represent the commonly used digital, cross-disciplinary archives for high-quality academic research [44].

To meet the study's objective, the set search words ((bio* plastic) AND packaging) AND (sustainab* OR environment* OR social OR econom*) AND (challenge OR risk OR drawback OR problem) were used.

The first search round was conducted between November 2021, and the search was complemented in March 2022. The primary data include journal articles published in academic journals, book chapters, and conference proceeding papers in order to maintain a

thorough coverage of the literature written in English. The database search was based on abstracts, keywords, and article titles. The time limit set was 2011–2021 in order to cover recent studies in the area. In March 2022, it was observed that several other articles were published within 2022, and, as a result, we decided to include these articles in the analyses, too. The summary of the research protocol is shown in Table 1.

Table 1. Summary of the research protocol.

Research Protocol	Description
Databases	Scopus, Web of Science,
Search field	Title-Abstract-Keywords
Search string	((bio* plastic) AND packaging) AND (sustainab* OR environment* OR social OR econom*) AND (challenge OR risk OR drawback OR problem)
Language	English
Data range	Beginning of 2011 until April 2022
Publication type	Peer-reviewed journals, book chapters, and conference papers
Inclusion criteria	Papers that mention environmental, social, and/or economic challenges of biobased plastic packaging products
Exclusion criteria	Papers that do not address any sustainability challenges in the abstract, keyword, or title, or papers that do not contain biobased plastic packaging products

The research process is summarized in Figure 2. The Web of Science returned 156 results, and Scopus returned 188 results. After duplicates were removed, a total of 232 documents were chosen for the abstract and title check. The abstracts and titles were checked with economic, environmental, and social sustainability in mind. After checking the abstracts and titles, 32 papers were chosen for detailed reading. After the eligibility was analyzed, 29 papers were chosen for the final check. Furthermore, these articles were subsequently checked for references in order to search for relevant important articles that may have been missed out in the search. As a result, five additional articles were added to the study in accordance with the backward snowballing strategy. Hence, a total of 34 articles were chosen for the analysis.

As can be seen from Figure 3, the number of articles published on the topic has been increasing significantly since 2017. In this research, articles published in 2022 only consider the first three months of the year. Hence, it can be expected that the number of articles published in 2022 will exceed the number of articles published in 2021 by fitting in the trend of increasing published articles. This increase in the published articles proves the increasing interest in the topic in academia and that this article is relevant and needed for further review of the studies to critically analyze the state of art in this field.

The data were analyzed qualitatively, utilizing content analysis, which is considered to provide a flexible method for analyzing textual data [45]. This process included the phases of data reduction, data display, the drawing of conclusions, and verification [46]. The analysis followed directed content analysis (see, e.g., [47]), in which the division into different life cycle stages (from BOL to MOL to EOL) was used as the starting point for the analysis of the data. Furthermore, the framework of the triple bottom line (economic, environmental, and social perspectives) guided the first level of coding.

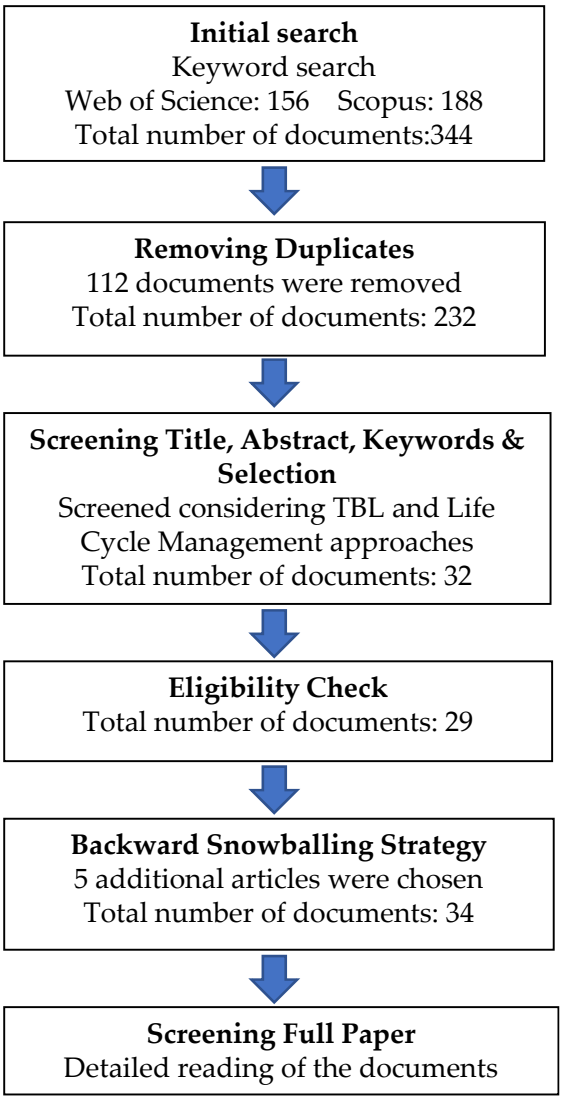

Figure 2. Research process.

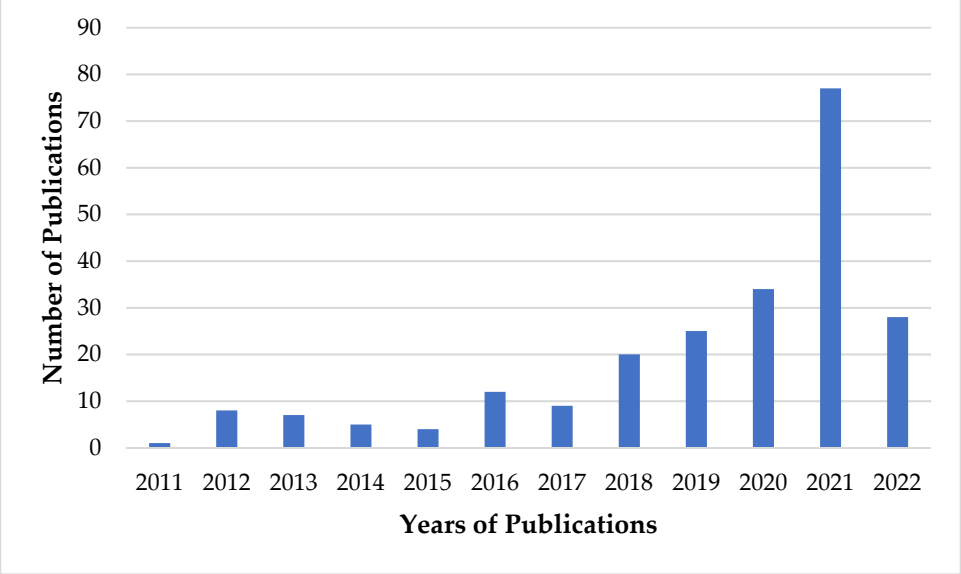

Figure 3. Number of publications distribution by year.

4. A Conceptual Framework for the Challenges Associated with Biobased Plastic Packaging

Overall, the literature on the topic focuses mostly on the technical challenges, opportunities, or possibilities related to technical product development. The review of the prior literature showed that research focusing on environmental, economic, and social challenges is limited. There are several studies focusing on the environmental challenges by conducting LCA studies on one or two life cycle stages. However, LCA studies that focus on the whole life cycle of this subject are very limited. Research on economic and social challenges is almost non-existent. In Table 2, the conceptual framework of challenges of biobased (plastic) packaging products, the identified challenges are summarized based on the life cycle phases they are connected: BOL, MOL (production and use), and EOL. Furthermore, the framework also includes some general challenges associated with several life cycle stages. The conceptual framework was formed on the basis of the literature analysis and also includes the categorization of the challenges in relation to the different sustainability aspects (economic, environmental, and social). It must, however, be noted that the categorization is not exact; different challenges may impact multiple categories.

Table 2. A conceptual framework of challenges of biobased (plastic) packaging products.

	Environmental Challenges	Economic Challenges	Social Challenges
Phase 1: Beginning of life: Resource Extraction	• Land use change decreasing space for food [6,8,10–19] • Loss of biodiversity [6,15] • Toxic pesticide and fertilizer use can create pollution [6,8,11,13,15–17] • Soil erosion and deforestation [6,15] • Eutrophication [6,12,15] • Use of GMOs [6,8,17,19] • Potential hazard in the workplace [8,17] • Decreasing water security [6,13,17] • Land use change increasing carbon emissions [6]	• Possible increase in food prices with the land use change [6,16,17]	• Toxic pesticides causing risk to human health [8,15,16,19] • Risk of exploitative working conditions in developing countries as they have low social standards [6,10] • Alienation and negative impacts on livability [10] • Land use change can alter ecosystems, increasing risk of zoonotic and infectious diseases [6]
Phase 2: Middle of Life: Production	• Efficiency in the use of water and energy [6,8,17,19]	• Because of the small market, redesign of production not being viable [48]	• Occupational health and safety hazard problems [6,8,17]
Phase 3: Middle of Life: Use	• Use of hazardous chemicals or petroleum-based co-polymers during production and processing [8,17,19]	• Low willingness to pay [21] • Low demand [12]	• Low willingness to pay [21] • Low demand [12] • Consumers preferring other types of packaging [48] • Added chemical substances during production can migrate from packaging to food and can cause human health problems [6]

Table 2. *Cont.*

	Environmental Challenges	Economic Challenges	Social Challenges
Phase 4: End of Life	• PET streams being contaminated with PLA causing poor-quality recycled PET [12,15,19,48] • Non-existing standards about biodegradability in water [17] • Lack of sorting infrastructure [21] • Lack of biodegradation/composting/recycling infrastructure [17,37,49,50] • Some packaging not degrading in marine environment for a long time [19] • Degradation of biodegradable plastic increasing GHG emissions when disposed into landfills [11,15,16] • Biodegradable materials contaminating organic solid waste treatment [51] • Biodegradation of certain plastics can release toxic substances that can pollute environment [6,19]	• Because of the small market, redesign of waste management system not being viable [6]	• Differences in waste management systems in different areas and countries [20] • Consumers not knowing how to separate waste [6,17,20,21] • Labeling not being clear and reliable [49,51] • Compostability claims as a license to litter [6,19,50] • Biodegredation of certain plastics can release toxic substances that can create risks to human health [6]
General	• Certification/label not being clear [6,19,51] • Not being necessarily sustainable [13,16,19] • No viable option that can meet performance criteria and is cost effective [12,17,37,38] • Circular economy debate on biodegradability [52]		

4.1. Economic Challenges

In the literature, there are not many studies discussing the economic challenges related to biobased products. In this paper, all the possible studies are examined within the scope in order to cover possible economic challenges mentioned in the literature. The economic problems associated with biobased plastic packaging products are linked to being more expensive than conventional plastics in general. PLA, starch, and PHAs are seen as the most economically viable materials for bioplastics, as they can be processed with pre-existing conventional converting equipment. There is also a demand for them, as they have satisfactory functional properties [53]. Because the market volume is small, major investment or the redesign of production and waste management systems is not economically viable [31]. However, if the market volume increases as expected, investment and redesign costs are expected to increase over time, making changes in the waste management system feasible.

The literature discusses how production costs can be reduced by economies of scale. However, because supply chains are long, increasing production volumes is likely to be challenging [54]. Moreover, a low production yield makes it hard to decrease prices [12]. Hence, even though a decrease in their price is expected, it remains unclear as to whether they will be priced competitively in relation to conventional plastics. Another discussion on the economic side concerns whether biobased products have the potential to affect food prices. The space they take up for planting may compete with food production space. The potential for less space for food production may create fluctuations in food pricing [1,10]. Overall, biobased polymers are more expensive than conventional solutions because the biorefinery (processing) part of the supply chain and feedstock acquisition is rather expensive [6]. High prices of biobased plastics create an economic barrier in the market, making it harder for them to become more widespread [11].

4.2. Environmental Challenges

There are environmental problems related to causing ecotoxicity and human health issues related to the use of hazardous chemicals or petroleum-based co-polymers during production and processing in order to increase brittleness, high oxygen permeation, and poor thermal properties [19], as well as a lack of efficiency in the use of water and energy during biomass production and processing [8,11]. Moreover, from the LCA perspective, it is not always clear what type of EOL option is environmentally better [1]. Nevertheless, the choice of EOL scenario has an important effect on overall environmental sustainability [4].

In the BOL stage, one important environmental observation concerns the need for feedstock and farming practices and their negative effects. The sustainability of a biobased product depends on the feedstock type used in the production. If the crops are first generation or second–third generation (non-edible), byproducts, residues, or wastes make a difference in terms of sustainability [15]. If the biomass used is from first-generation stocks, crop cultivation conditions become important factors; for example, the land used for the crop type and the amount and type of pesticides and fertilizers used [13]. There are also problems with biobased plastics that stem from the biobased feedstock growth creating issues due to the toxic pesticides used, which can pollute water and soil and have an impact on wildlife [8]. When it comes to eutrophication and stratospheric ozone depletion, biobased products perform worse than their petroleum-based plastic counterparts [15]. The use of GMOs to grow feedstock is a problem, as the effects of GMOs are not well understood and can lead to human health issues [8]. Water security may also be a problem in certain areas, such as Brazil and Asia, where most of the biomass is grown for biobased plastic production [6].

If the crops used are the first generation, the space used for planting may compete with food production space. Land use change can cause problems such as biodiversity loss, soil erosion, eutrophication, and ecosystem change [6]. Land use change also has the potential to increase carbon emissions. If the global biobased plastic consumption increases by 5%, carbon emissions related to the land use change could be offset in 22 years [55]. When many scholars assume that biobased products are carbon neutral, as the growing biomass removes carbon from the atmosphere, they often do not calculate land use change [10]. If the demand for biomass increases, there will be land use change causing deforestation, as new land may need to be opened by eliminating existing forest space [15]. The use of wood as a feedstock has brought with it issues in terms of deforestation [19].

In the MOL stage, efficiency in the use of water and energy in production is one of the crucial problems [6,8,17,19]. The biorefinery and polymerization processes that are used for converting feedstock to plastic are known to be highly energy intensive, sometimes more energy intensive than conventional plastic production [6], and the production of certain biopolymers such as PLA and TPS (Thermoplastic Starch) creates a high amount of wastewater [56] The chemicals added during production that can be toxic and environmentally harmful to wildlife when the products are discarded in the environment [17].

Some of the most pressing issues belong to the EOL stage. From the LCA perspective, according to some researchers, it is not clear what type of EOL option is better [1]. However, the choice of EOL scenario has an important effect on the overall environmental sustainability [4]. The plastic recycling system is already complicated and does not work well enough. An increase in biobased plastic packaging can increase the complications in terms of the identification and sorting process. Strong, clear labeling is needed [56].

The main issues related to the EOL options of these products often concern the regulations, lack of infrastructure, or customer use. This situation is also an issue in terms of checking the sustainability of the products, as it is often unknown whether the intended end-of-life design works in the real world [4]. In general, because the market share of bioplastics is still relatively small, large-scale sorting and recycling infrastructure often does not exist. Moreover, different countries have different infrastructures or lack infrastructure, especially when it comes to biodegradable plastics. For example, in Germany, biodegradable plastics are often incinerated, and composting is uncommon because biobased plastics

are recognized as contaminants in the sorting facilities [4]. Therefore, not knowing the countries in which the products will be used makes it even more challenging for companies to estimate the EOL risks.

Even though many products on the market are labeled as biodegradable, the exact composition of the product is not explained. The contents of the polymer and the additives used in the product determine the biodegradability and the time needed for biodegradation. Some biodegradable products can only degrade in certain composting facilities and not in the biomass section of the municipal waste. This can create a problem, as some biobased products can contaminate municipal waste [51]. For the municipal composting facilities to address compostable packaging and not only home biowaste, certain technical modifications will be required, particularly at the level of pre-processing, to ensure an efficient composting process for the packaging [57]. Additionally, if biodegradable products end up in landfill and do not degrade in facilities, they can increase greenhouse gas emissions. The degradation of biodegradable plastics may lead to significant greenhouse gas emissions (CO_2 and CH_4) if they are disposed of in landfills [11,56]. The dissolving of certain biodegradable materials in marine environments is also another problem. PLA can stay in a marine environment for up to one thousand years [58].

There is also a wide-reaching discussion about biodegradable plastics, according to which recycling should be the preferred EOL option instead of composting and biodegradation [15,56,59] as it creates more need for virgin materials. Moreover, there are questions raised if biobased biodegradable products follow circular economy guidelines or not [4]. The Ellen MacArthur Foundation suggests that biodegradable/compostable materials should be used only for specific applications, such as garbage bags for organic waste, and efficiently recyclable biobased products should be preferred for other uses [59].

Recycling can be a preferred alternative in comparison to biodegradation when the carbon cycle is taken into consideration. If biodegradable materials such as PHAs and PLAs could be effectively recycled in the current system, feedstock use could be decreased, a sustainable circular economy could be achieved, and the prices would drop [60]. Mendes and Pedersen, Briassoulis et al., and Hottle et al. [15,48,56] suggest that PLA, the most used biodegradable plastic packaging, can also be mechanically recycled. Additionally, according to an LCA conducted, PLA should be the preferred option [15]. However, PLA should be separately recycled from other conventional plastics. The recycling stream for PLA does not exist.

There are also issues regarding the reliability of labeling [61], especially in relation to biodegradability, due to problems such as limited methodology, unrealistic testing conditions, a lack of guidance for employing different test materials, and insufficient statistical power [19]. For example, there are European standards for assessing the biodegradability and compostability of biobased plastics in industrial composting institutions and soil. Additionally, there is no European Standard for assessing biodegradability in water, as the variability of water conditions makes standardization difficult [32]. Moreover, biobased plastics are often labeled as "other plastic", resin identification number 7, which often makes customers think that they are non-recyclable or non-compostable [6].

The literature examines customers not knowing how to dispose of biobased products, a situation that creates a big problem. Customers often believe all bioplastics are home compostable when they can, in fact, only be recycled or composted in facilities. Many biodegradable polymers compose very slowly in home composting, and they need to be composted in industrial facilities instead [4,62]. This is especially a pressing issue for PLA, the most used biobased material for biodegradable plastics, which takes over three decades to degrade in soil [63] and needs composting in industrial conditions [4]. For this to be achieved, the quantity and sorting efficiency needs to be increased [48]. Tucker and Johnson [64] have also discussed the fact that the biodegradation of biobased plastics in nature can cause cytotoxic or phototoxic material release, both of which are dangerous for human health and the environment.

Mendes and Pedersen [15] noted that, compared to landfilling, mechanical recycling, anaerobic digestion and incineration, and industrial composting may have higher negative environmental impacts. Additionally, composting PLA that has very low macronutrients cannot create fertilizers through composting.

Some biobased biodegradable products (especially PLA) can look like conventional products (especially PET), and customers can end up sorting them in the plastic recycling bins alongside non-biodegradable conventional products. Contamination of the recycled plastic streams results in poor-quality recycled conventional plastic [19,60]. It has been observed that even a very low level of contamination in the PET waste streams can make the stream unsuitable for mechanical recycling. This also creates economic problems. There is, so far, no system available for the separation of PLA from PET. Even though it is doable, it does not exist due to the costs [65]. Moreover, some scholars have raised concerns about customers believing that compostable biobased plastics can compost in nature without the need for specific composting facilities. This behavior can increase littering and the disposal of products in nature instead of using trash cans or specific composting facilities. This phenomenon is referred to as 'the license to litter' in the literature [6,19,50].

4.3. Social Challenges

Social sustainability issues are usually related to the fact that feedstock is cultivated in Asia or South America and the BOL stage of the products. Because most biobased materials are cultivated in countries with low social standards and weak legislation, there are issues related to poverty and several social risks [10]. Exploitative working conditions, alienation, and the negative impacts on livability and communities are identified as social risks, especially for indigenous groups in the study conducted in Indonesia by [66]. Hence, the country of origin of the feedstock and the working conditions in those countries are important. Considering the forecasted ongoing growth in the Asian markets [10], these problems are likely to increase.

Raw material extraction and the production of biobased materials can cause risks to human health. The use of GMOs for the growth of biomass can create allergic reactions and alterations in the metabolic pathway [8]. The use of a hazardous mix of substances during production and processing can create risks to human health when the workers are exposed to these substances, as they can cause burns and irritation to the eyes, skin, and upper respiratory systems with dermal contact. They are also combustible, creating a risk of explosions in the workplace. The physical extraction of PHA is reported to expose workers to certain carcinogenic substances, which can create serious health issues, including unconsciousness and coma [6].

Labels exist to make it easier for customers to navigate the EOL options. However, labeling is often unclear, and packaging can be labeled as 'compostable', 'biodegradable', or 'biobased'. The meaning of these terms is often confusing for customers [49]. Hence, even though the products are labeled correctly, bad practices can exist due to confusing labeling [32]. Moreover, many products in the market are labeled as biodegradable, but the composition of the polymers and additives are not provided. This composition influences biodegradability and the time needed for degradation. As a result, consumers do not know how to dispose of the product [50].

According to a study conducted in Australia by Dilkes-Hoffman et al. in 2019 [41], public knowledge of biobased plastics is so low that some customers assume biobased plastics are always biodegradable. However, the perception is positive as they are perceived as being better than conventional or recycled plastics. In a study conducted in Germany by Klein et al. [41] reached the conclusion that biobased plastics are perceived well by customers. Herbes et al. [67] conclude in their study that biodegradability is preferred to only being biobased. The research also shows that customers are not aware of how to dispose of biobased plastic packaging. In the study conducted by Dilkes-Hoffman et al. in 2019 [41], 62% of the customers said that they would dispose of biobased plastics in a regular recycling bin. In a study conducted by Taufik et al. [20], being biobased and

biodegradable confused customers as they believed plastics, even though biobased, can be only recyclable. Customers' high willingness to buy biobased packaging products even though they do not know how to properly dispose of them shows a clear challenge about the EOL of these products.

One important aspect regarding biobased packaging is that instead of biobased, some consumers may prefer recycled plastic or paper/glass packaging over biobased plastic packaging [49].

5. Discussion and Concluding Remarks

The literature clearly shows that the sustainability of biobased plastic packaging depends on many factors, such as the type of feedstock used, the farming conditions during the growth of the biomass, the available EOL options, and if the end users can appropriately dispose of these products.

The first attempt in this study was to create a literature review that focuses on all biobased packaging types. However, when the search words "biobased packaging" or "bio-based packaging" were used, almost all the answers were related to "biobased plastic packaging". This shows that most research about biobased products is on biobased plastics and their challenges. Even though wood or bamboo fiber packaging and even some forms of paper-based packaging are considered to be biobased, they were rarely represented in these specific keyword search results. Hence, keywords are revised to be "bio* plastic packaging" in order to cover the literature on the biobased plastic packaging area.

Different domains of sustainability challenges can interact with each other. Environmental problems in resource extraction, such as decreasing water security, soil degradation, and eutrophication, can have a negative impact on human health, and this can cause economic challenges due to decreasing human labor power. The economic challenge of a possible increase in food prices can lead to malnutrition and have effects on local communities (social). A low willingness to pay (social) during the use phase can prevent the product prices from dropping further, and this keeps the market small. As the market is small, redesigning production would not be viable (economic), and the infrastructure cannot be developed to have better recycling systems (environmental). Social challenges in the EOL phase, such as consumers not knowing how to separate, would create environmental challenges by waste streams being mixed and recycled materials being of poor quality.

The main identified challenges of biobased packaging products were related to biomass cultivation and farming that can create water stress, pesticides creating environmental pollution and health risks, possible land use change causing competition with food production and thus causing problems with food availability and high food prices, biodiversity and deforestation, customers not knowing how to dispose of products, and the lack of infrastructure for end-of-life options. To manage these challenges, better regulation and control at all stages of the life cycle, companies taking responsibility to follow their supply chain and choose responsible business practices, as well as communicating the correct disposal options to their customers, better labeling and education of customers are needed.

In terms of the theoretical implications, this study has increased our comprehensive understanding of the challenges associated with biobased packaging products. The study not only highlights the different challenges in different life cycle phases but also connects them with different sustainability dimensions going beyond the state of the art of the research in the field (e.g., Gerassimidou et al. [6]), giving recommendations for companies and pointing out the challenges associated with biobased plastic packaging products without comparison to other products. This provides a starting point for the development of different assessment tools to assess the sustainability impacts of different packaging products. Based on this, this study raises important questions that provide avenues for future research on more detailed data, as well as assessment tools to assess the sustainability of biobased packaging products regarding the different sustainability aspects.

This study is one of the first to address the social perspective on the challenges associated with biobased packaging products. Based on these, we can ask, e.g., the following:

- What are the working conditions in the raw material extraction/ production stage?
- How is the social community affected by biomass growth?
- What can be done to increase consumers' awareness of the correct EOL options?

Expanding the research to cover qualitative data from consumers and companies would provide a fruitful avenue to examine the challenges regarding production, usage, and EOL habits. Moreover, expanding the research about what the mitigation strategies are for the mentioned challenges and what and how much actually the companies are doing to mitigate the mentioned challenges would provide a fruitful avenue for future research.

The present study concluded that the economic challenges associated with the products in question are not well presented in the literature, besides brief mentions that they are expensive. What can be done to decrease their prices? Our study also concluded that there are not many articles addressing the use phase of these products. It would be important to conduct further research into the possible environmental and health effects of the use phase

With regards to managerial implications, the conceptual framework presented in the study provides a tool to identify the possible challenges associated with the products that companies are developing. Thus, this is a framework to anticipate possible challenges and risks and to develop additional tools to manage them. This tool can be used by company operators to manage biobased packaging challenges. Moreover, being aware of these challenges can help them more effectively communicate the specifics of biobased plastics to their customers. Communicating biobased plastics as if they are truly sustainable without being aware of their challenges can create the risk of greenwashing customers and reputational risks. Moreover, knowing that there are social risks related to the customers, that there are issues regarding labeling not being clear, and regarding customers not knowing how to sort the waste correctly can help businesses design packaging for the easy and correct use/disposal of their products. Furthermore, being aware of the issues related to the lack of infrastructure and regulations changing in different countries can help businesses take these issues into consideration during the design process.

Design that takes into account the EOL challenges is needed. Customers often do not know how to separate waste correctly, or they do not know how to read the labels. Some countries do not even have the necessary infrastructure. Considering where the products will be sold, recycling and composting infrastructure in the targeted sales country should be considered while designing the product. If there are no composting or biodegradation facilities, or if the customers cannot easily reach them, recyclable products in the current system should be preferable. When recyclable products are designed, all efforts should be made to ensure that the type of product can be recycled in that country's system. Moreover, making sure labels and disposal instructions are clear and easy for the customers to understand and follow is an important aspect for the companies.

In conclusion, biobased packaging products are not always more sustainable. Companies need to analyze their product life cycles carefully, be aware of the possible challenges and act accordingly.

As is the case with all studies, this study also has its limitations. This study is limited by the fact that it does not cover empirical data; instead, the analysis was based on peer-reviewed articles complemented with selected gray literature supporting the knowledge gaps. Furthermore, there may also be additional relevant articles in other types of literature sources, such as government reports or project evaluation reports, that would provide insights for the analysis. Although the research was complemented by Google searches for gray literature, there was a high degree of variety in the documents (such as commercial reports and news articles), and this increased the number of irrelevant articles. Thus, the detailed analysis of all the search results was considered unnecessary. Furthermore, the set search words have their limitations. The review revealed that the words "bioplastic packaging" or "biobased plastic packaging" are used almost synonymously with "biobased packaging". Hence, there may be certain articles that work on biobased plastic packaging by using the term "biobased packaging". Those articles could not be included in the data set, as the search words were "bio* plastic packaging". Moreover, there may be articles that work

on 'biobased products' without mentioning 'packaging', and these are excluded from the data set. To limit the search results with the aim of focusing on packaging specifically, search words are limited. In this expanding research field, further detailed systematic reviews of literature with possible citation/co-citation analyses could also provide a potential avenue for future study.

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References

1. Gustavo, J.U., Jr.; Pereira, G.M.; Bond, A.J.; Viegas, C.V.; Borchardt, M. Drivers, opportunities and barriers for a retailer in the pursuit of more sustainable packaging redesign. *J. Clean. Prod.* **2018**, *187*, 18–28. [CrossRef]
2. Cruz-Romero, M.; Kerry, J. Crop-based biodegradable packaging and its environmental implications. CAB Reviews: Perspectives in Agriculture, Veterinary Science. *CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour.* **2008**, *3*, 1–25.
3. Smithers. *The Future of Global Packaging to 2024*; Smithers: Akron, OH, USA, 2019.
4. Reichert, C.L.; Bugnicourt, E.; Coltelli, M.-B.; Cinelli, P.; Lazzeri, A.; Canesi, I.; Braca, F.; Martínez, B.M.; Alonso, R.; Agostinis, L.; et al. Bio-Based Packaging: Materials, Modifications, Industrial Applications and Sustainability. *Polymers* **2020**, *12*, 1558. [CrossRef] [PubMed]
5. Stark, N.M.; Matuana, L.M. Trends in Sustainable Biobased Packaging Materials: A Mini Review. *Mater. Today Sustain.* **2021**, *14*, 100084. [CrossRef]
6. Gerassimidou, S.; Martin, O.V.; Chapman, S.P.; Hahladakis, J.N.; Iacovidou, E. Development of an integrated sustainability matrix to depict challenges and trade-offs of introducing bio-based plastics in the food packaging value chain. *J. Clean. Prod.* **2021**, *286*, 125378. [CrossRef]
7. Johansson, C.; Bras, J.; Mondragon, I.; Nechita, P.; Plackett, D.; Šimon, P.; Svetec, D.G.; Virtanen, S.; Baschetti, M.G.; Breen, C.; et al. Renewable Fibers and Bio-based Materials for Packaging Applications–A Review of Recent Developments. *BioResources* **2012**, *7*, 2506–2552. [CrossRef]
8. Álvarez-Chávez, C.R.; Edwards, S.; Moure-Eraso, R.; Geisera, K. Sustainability of bio-based plastics: General comparative analysis and recommendations for improvement. *J. Clean. Prod.* **2012**, *23*, 47–56. [CrossRef]
9. Oever, M.v.d.; Molenveld, K.; Zee, M.v.d.; Bos, H. *Bio-Based and Biodegradable Plastics—Facts and Figures*; Wageningen Food & Biobased Research: Wageningen, The Netherlands, 2017.
10. Spierling, S.; Knüpffer, E.; Behnsen, H.; Mudersbach, M.; Krieg, H.; Springer, S.; Albrecht, S.; Herrmann, C.; Endres, H.-J. Bio-based plastics—A review of environmental, social and economic impact assessments. *J. Clean. Prod.* **2018**, *185*, 476–491. [CrossRef]
11. Coppola, G.; Gaudio, M.T.; Lopresto, C.G.; Calabro, V.; Curcio, S.; Chakraborty, S. Bioplastic from Renewable Biomass: A Facile Solution for a Greener Environment. *Earth Syst. Environ.* **2021**, *5*, 231–251. [CrossRef]
12. Mtibe, A.; Motloung, M.P.; Bandyopadhyay, J.; Ray, S.S. Synthetic Biopolymers and Their Composites: Advantages and Limitations—An Overview. *Macro Mol. Rapid Commun.* **2021**, *42*, 2100130. [CrossRef]
13. Sousa, A.F.; Patrício, R.; Terzopoulou, Z.; Bikiaris, D.N.; Stern, T.; Wenger, J.; Loos, K.; Lotti, N.; Siracusa, V.; Szymczyk, A.; et al. Recommendations for replacing PET on packaging, fiber and film materials with biobased. *Green Chem.* **2021**, *23*, 8795–8820. [CrossRef]
14. Kochańska, E.; Łukasik, R.M.; Dzikuć, M. New Circular Challenges in the Development of Take-Away Food Packaging in the COVID-19 Period. *Energies* **2021**, *14*, 4705. [CrossRef]
15. Mendes, A.C.; Pedersen, G.A. Perspectives on sustainable food packaging: Is bio-based plastics a solution? *Trends Food Sci. Technol.* **2021**, *112*, 839–846. [CrossRef]
16. Atiwesh, G.; Mikhael, A.; Parrish, C.C.; Banoub, J.; Le, T.-A.T. Environmental impact of bioplastic use: A review. *Heliyon* **2021**, *7*, e07918. [CrossRef]

17. de Castro, T.R.; de Macedo, D.C.; de Genaro Chiroli, D.M.; da Silva, R.C.; Tebcherani, S.M. The Potential of Cleaner Fermentation Processes for Bioplastic Production: A Narrative Review of Polyhydroxyalkanoates (PHA) and Polylactic Acid (PLA). *J. Polym. Environ.* **2021**, *30*, 810–832. [CrossRef]
18. Koller, M. Switching from petro-plastics to microbial polyhydroxyalkanoates (PHA): The biotechnological escape route of choice out of the plastic predicament? *EuroBiotech J.* **2019**, *3*, 32–44. [CrossRef]
19. Ferreira-Filipe, D.A.; Paço, A.; Duarte, A.C.; Rocha-Santos, T.; Patrício Silva, A.L. Are Biobased Plastics Green Alternatives?—A Critical Review. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7729. [CrossRef]
20. Taufik, D.; Reinders, M.J.; Molenveld, K.; Onwezen, M.C. The paradox between the environmental appeal of bio-based plastic packaging for consumers and their disposal behaviour. *Sci. Total Environ.* **2020**, *705*, 135820. [CrossRef]
21. Mehta, N.; Cunningham, E.; Roy, D.; Cathcart, A.; Dempster, M.; Berry, E.; Smyth, B.M. Exploring perceptions of environmental professionals, plastic processors, students and consumers of bio-based plastics: Informing the development of the sector. *Sustain. Prod. Consum.* **2021**, *26*, 574–587. [CrossRef]
22. Elkington, J. *Cannibals with Forks: The Triple Bottom Line of the 21st Century*; Stoney Creek: New Society Publishers: Gabriola, BC, Canada, 1998.
23. Gimenezn, C.; Sierra, V.; Rodon, J. Sustainable operations: Their impact on the triple bottom line. *Int. J. Prod. Econ.* **2012**, *140*, 149–159. [CrossRef]
24. Jum'a l Zimon, D.; Ikram, M.; Madzík, P. Towards a sustainability paradigm; the nexus between lean green practices, sustainability-oriented innovation and Triple Bottom Line. *Int. J. Prod. Econ.* **2022**, *245*, 108393.
25. Lerman, L.V.; Benitez, G.B.; Gerstlberger, W.; Rodrigues, V.P.; Frank, A.G. Sustainable conditions for the development of renewable energy systems: A triple bottom line perspective. *Sustain. Cities Soc.* **2021**, *75*, 103362. [CrossRef]
26. Morelli, J. Environmental sustainability: A definition for environmental professionals. *J. Environ. Sustain.* **2011**, *1*, 2.
27. Kiritsis, D.; Bufardi, A.; Xirouchakis, P. Research issues on product lifecycle management and information tracking using smart embedded systems. *Adv. Eng. Inform.* **2003**, *17*, 189–202. [CrossRef]
28. European Bioplastics. What Are Bioplastics? Available online: https://www.european-bioplastics.org/bioplastics/ (accessed on 1 November 2021).
29. Lee, R.A.; Lavoie, J.-M. From first—To third-generation biofuels: Challenges of producing a commodity from a biomass of increasing complexity. *Anim. Front.* **2013**, *3*, 6–11. [CrossRef]
30. WMuhamad, N.A.W.; Othman, R.; Shaharuddin, R.I.; Hasni, M.S.I. Microorganisms as Plastic Biodegredation Agent towards Sustainable Environment. *Adv. Environ. Biol.* **2015**, *9*, 8–13.
31. Bartolo, A.D.; Infurna, G.; Dintcheva, N.T. A Review of Bioplastics and Their Adoption in the Circular Economy. *Polymers* **2021**, *13*, 1229. [CrossRef]
32. European Environment Agency. *Biodegradable and Compostable Plastics—Challenges and Opportunities*; European Environment Agency: Copenhagen, Denmark, 2020.
33. Nilsen-Nygaard, J.; Fernández, E.N.; Radusin, T.; Rotabakk, B.T.; Sarfraz, J.; Sharmin, N.; Sivertsvik, M.; Sone, I.; Pettersen, M.K. Current status of biobased and biodegradable food packaging materials: Impact on food quality and effect of innovative processing technologies. *Compr. Rev. Food Sci. Food Soc.* **2021**, *20*, 1333–1380. [CrossRef]
34. Reddy, M.M.; Vivekanandhan, S.; Misra, M.; Bhatia, S.K.; Mohanty, A.K. Biobased plastics and bionanocomposites: Current status and future opportunities. *Polym. Polym. Sci.* **2013**, *38*, 1653–1689. [CrossRef]
35. Tokiwa, Y.; Calabia, B.P.; Ugwu, C.U.; Aiba, S. Biodegradability of Plastics. *Int. J. Mol. Sci.* **2009**, *10*, 3722–3742. [CrossRef]
36. European Bioplastics. Frequently Asked Questions on Bioplastics. 2021. Available online: https://docs.european-bioplastics.org/publications/EUBP_FAQ_on_bioplastics.pdf (accessed on 30 October 2021).
37. Epps, T.H.; Korley, L.T.J.; Yan, T.; Beers, K.L.; Burt, T.M. Sustainability of Synthetic Plastics: Considerations in Materials Life-Cycle Management. *JACS Au* **2022**, *2*, 3–11. [CrossRef] [PubMed]
38. Thakur, S.; Chaudhary, J.; Sharma, B.; Verma, A.; Tamulevicius, S.; Thakur, V.K. Sustainability of bioplastics: Opportunities and challenges. *Curr. Opin. Green Sustain. Chem.* **2018**, *13*, 68–75. [CrossRef]
39. Daia, B.; Gu, X.; Xie, B. Policy Framework and Mechanism of Life Cycle Management of Industrial Land (LCMIL) in China. *Land Use Policy* **2020**, *99*, 104997. [CrossRef]
40. Sinha, P.; Kriegner, C.J.; Schew, W.A.; Kaczmar, S.W.; Traister, M.; Wilson, D.J. Regulatory policy governing cadmium-telluride photovoltaics: A case study contrasting life cycle management with the precautionary principle. *Energy Policy* **2008**, *36*, 381–387. [CrossRef]
41. Dilkes-Hoffman, L.S.; Pratt, S.; Lant, P.A.; Laycock, B. The role of biodegradable plastic in solving plastic solid waste accumulation. In *Plastics to Energy*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 469–505.
42. Klein, F.; Emberger-Klein, A.; Menrad, K.; Möhring, W.; Blesin, J.-M. Influencing factors for the purchase intention of consumers choosing bioplastic products in Germany. *Sustain. Prod. Consum.* **2019**, *19*, 33–43. [CrossRef]
43. Chen, W.; Oldfield, T.L.; Cinelli, P.; Righetti, M.C.; Holden, N.M. Hybrid life cycle assessment of potato pulp valorisation in biocomposite production. *J. Clean. Prod.* **2020**, *269*, 122366. [CrossRef]
44. Fahimnia, B.; Sarkis, J.; Davarzani, H. Green supply chain management: A review and bibliometric analysis. *Int. J. Prod. Econ.* **2015**, *162*, 101–114. [CrossRef]

45. Cavanagh, S. Content analysis: Concepts, methods and applications: Content analysis is a flexible methodology that is particularly useful to nurse researchers, asserts Stephan Cavanagh. *Nurse Res.* **1997**, *4*, 5–16. [CrossRef]
46. Miles, M.B.; Huberman, A.M. *Qualitative Data Analysis: An Expanded Source Book*, 2nd ed.; Sage: Thousand Oaks, CA, USA, 1994; ISBN 978-0-8039-4653-8.
47. Hsieh, H.F.; Shannon, S.E. Three Approaches to Content Analysis. *Qual. Health Res.* **2005**, *15*, 1277–1288. [CrossRef]
48. Briassoulis, D.; Pikasi, A.; Hiskakis, M. Recirculation potential of post-consumer /industrial bio-based plastics through mechanical recycling—Techno-economic sustainability criteria and indicators. *Polym. Degrad. Stab.* **2021**, *183*, 109217. [CrossRef]
49. Lorencatto, A.L.; Michie, S.; Miodownik, M. Barriers and Enablers to Buying Biodegradable and Compostable Plastic Packaging. *Sustainability* **2021**, *13*, 1463.
50. Kawashima, N.; Yagi, T.; Kojima, K. How Do Bioplastics and Fossil-Based Plastics Play in a Circular Economy? *Macro Mol. Mater. Enginering* **2019**, *304*, 1900383. [CrossRef]
51. Zaborowska, M.; Bernat, K.; Pszczółkowski, B.; Wojnowska-Baryła, I.; Kulikowska, D. Challenges in Sustainable Degradability of Bio-Based and Oxo-Degradable Packaging Materials during Anaerobic Thermophilic Treatment. *Energies* **2021**, *14*, 4775. [CrossRef]
52. Rosemboom, J.G.; Langer, R.; Traverso, G. Bioplastics for a circular economy. *Nat. Rev. Mater.* **2022**, *7*, 117–137. [CrossRef]
53. Scarfato, P.; Di Maio, L.; Incarnato, L. Recent advances and migration issues in biodegradable polymers from renewable sources for food packaging. *J. Appl. Polym. Sci.* **2015**, *132*, 42597. [CrossRef]
54. Storz, H.; Vorlop, K.-D. Bio-based plastics: Status, challenges and trends. *Appl. Agric. For. Res.* **2013**, *4*, 321–332.
55. Escobar, N.; Haddad, S.; Boerner, J.; Britz, W. Land use mediated GHG emissions and spillovers from increased consumption of bioplastics. *Environ. Res. Lett.* **2018**, *13*, 125005. [CrossRef]
56. Hottle, T.A.; Bilec, M.M.; Landis, A.E. Sustainability assessments of bio-based polymers. *Polym. Degrad. Stabil.* **2013**, *98*, 1898–1907. [CrossRef]
57. Rujnic-Sokele, M.; Pilipovic, A. Challenges and opportunities of biodegradable plastics: A mini review. *Waste Manag. Res.* **2017**, *35*, 132–140. [CrossRef]
58. Naser, A.Z.; Deiab, I.; Darras, B.M. Poly(lactic acid) (PLA) and polyhydroxyalkanoates (PHAs), green alternatives to petroleum-based plastics: A review. *RSC Adv.* **2021**, *11*, 17151–17196. [CrossRef]
59. World Economic Forum, Ellen Macarthur Foundation, McKinsey & Company. *The New Plastics Economy—Rethinking the Future of Plastics 2016*; Ellen Macarthur Foundation: Cowes, UK, 2016.
60. Maga, D.; Hiebel, M.; Aryan, V. A Comparative Life Cycle Assessment of Meat Trays Made of Various Packaging Materials. *Sustainability* **2019**, *11*, 5324. [CrossRef]
61. Majer, S.; Wurster, S.; Moosmann, D.; Ladu, L.; Sumfleth, B.; Thrän, D. Gaps and Research Demand for Sustainability Certification and Standardisation in a Sustainable Bio-Based Economy in the EU. *Sustainability* **2018**, *10*, 2455. [CrossRef]
62. Hong, M.; Chen, E. Chemically recyclable polymers: A circular economy approach to sustainability. *Green Chem.* **2017**, *19*, 3692–3706. [CrossRef]
63. Narancic, T.; O'Connor, K. Plastic waste as a global challenge: Are biodegradable plastics the answer to the plastic waste problem? *Microbiology* **2019**, *165*, 129–137. [CrossRef] [PubMed]
64. Tucker, N.; Johnson, M. *Low Environmental Impact Journals*; iSmithers Rapra Publishing: Shrewsbury, UK, 2004.
65. Siddiqui, M.N.; Redhwi, H.H.; Al-Arfaj, A.A.; Achilias, D.S. Chemical Recycling of PET in the Presence of the Bio-Based Polymers, PLA, PHB and PEF: A Review. *Sustainability* **2021**, *13*, 10528. [CrossRef]
66. Manik, Y.; Leahy, J.; Halog, A. Social life cycle assessment of palm oil biodiesel: A case study in Jambi Province of Indonesia. *Int. J. Life Cycle Assess.* **2013**, *18*, 1386–1392. [CrossRef]
67. Herbes, C.; Beuthner, C.; Ramme, I. Consumer attitudes towards biobased packaging—A cross-cultural comparative study. *J. Clean. Prod.* **2018**, *194*, 203–218. [CrossRef]

Publication II

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The dark side of sustainable packaging: Battling with sustainability tensions

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The dark side of sustainable packaging: Battling with sustainability tensions

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ABSTRACT

The sustainable packaging industry plays a significant role in tackling the major sustainability challenges of municipal waste and plastic consumption. While innovative sustainable packaging products offer alternatives to plastic packages made from fossil fuels, their production also poses sustainability problems, defined as tensions in this study. This study explores the different tensions of sustainable packaging production using the field of biobased packaging as an example of an innovative emerging industry. Moreover, the study illustrates different management strategies companies adopt to avoid, lower, and facilitate the identified tensions by taking the paradox management theory perspective. Based on qualitative, semi-structured interviews of 14 international companies working in various supply chain phases of the industry, this study identifies 20 distinct types of economic, structural, psychological, and behavioral tensions, demonstrating their characteristics and 12 strategies companies have adopted to manage these tensions. High investment and operating costs, lacking standards and guidelines, varying regulations among countries and regions, changing regulations, lack of knowledge of policy makers, consumers and end of life management companies are found to be causing most of the tensions. Joining associations, partnering with NGOs, obtaining labels and certifications, conducting LCAs are found to be among the most popular management strategies to the tensions. Overall, this study contributes to the emerging literature about the dark side of sustainability and answers the call for empirical research on the unintended consequences of sustainable production and their management; especially in the emerging industries. From a managerial perspective, this study provides insights into potential management actions of sustainability tensions and situations where government intervention is needed.

1. Introduction

Packaging is an important part of the product, creating barrier properties for the goods and giving the consumers important information about the product, such as size, price, and ingredients. As much as it is essential to the overall product, it is also a waste-generating medium (Jestratijevic et al., 2022) that creates negative impacts related to manufacturing, transportation, end-of-life (EOL) and raw material extraction (Gustavo Jr et al., 2018). Decisive regulatory actions, shifting consumer preferences, and public concerns (Diggle and Walker, 2020; Phelan et al., 2022), together with cost pressure, the rise of e-commerce and digitization are driving significant changes in sustainable consumer packaging (Phelan et al., 2022). Sustainable packaging refers to developing considerations, systems and materials in the packaging product's entire life cycle that addresses the social, environmental and economic sustainability aspects (Nordin and Selke, 2010). Companies have developed many forms of sustainable packaging, such as reusable and recyclable, fiber-based and biobased plastics packaging, in response to the rising demand for alternatives from businesses, particularly to the consumption of fossil-based plastics (Meherishi et al., 2019). Although these products have significant sustainability advantages in decreasing dependency on fossil-based resources (Ferreira-Filipe et al., 2021), they also pose their own sustainability challenges. These challenges represent tensions, i.e., unintended consequences, and conflicts between economic, environmental, and social goals (Govindan et al., 2021; Hahn et al., 2015) that producers of sustainable packaging and their stakeholders need to cope with (Pålsson and Sandberg, 2020). These tensions include, for example, the creation of harmful environmental emissions due to the use of specific raw materials and technologies, increasing waste due to lacking EOL infrastructures preventing them from serving the circular economy, and not being competitive in prices with conventional products (fossil-based plastics) (Ferreira-Filipe et al., 2021; Gerassimidou et al., 2021). The emergence of these tensions represents the so-called "dark side of sustainability" (e.g., Tura et al., 2019)

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increasingly acknowledged to be an important area for research beyond sustainable production's positive effects and win-win situations (Chen et al., 2021; Pålsson and Sandberg, 2021).

To manage tensions, there is a need to broaden the understanding of their characteristics, complexity, and variety (Van der Byl and Slawinski, 2015; Schad and Bansal, 2018). This need has been acknowledged within different research streams, such as in logistics and supply chain literature (Zehendner et al., 2021) and corporate social responsibility (CSR) literature (Siltaloppi et al., 2021). The need to manage tensions has acknowledged also in regarding stakeholder and marketing (Longo et al., 2019; Tóth et al., 2018), and organizational theories (Smith and Lewis, 2011). Furthermore, previous research highlights the need for empirical studies to increase the understanding of the different types of tensions and to identify possible strategies for their management (Brix-Asala et al., 2018; Joseph et al., 2020; Sundqvist-Andberg and Åkerman, 2021).

Emerging industries are industries that are either at the earliest stage of their development or at the learning stage in their early maturity and stability phase (Forbes and Kirsch, 2011). They are increasingly seen as catalysts for transformative, sustainability change (Gong et al., 2022). Although emerging industries may bring multiple opportunities and possibilities for companies (such as minimal competition, high growth potential and low entry barriers), they are also connected to high uncertainty creating extra tensions compared to established industries (Forbes and Kirsch, 2011; Gustafsson et al., 2016; Phall et al., 2011). These tensions are linked to development challenges (Moeen et al., 2020) such as difficulties in obtaining raw materials, high initial costs, lack of infrastructure and customer confidence (Porumboiu, 2020). Studying sustainability tensions from the emerging industry perspective can improve these industries' contribution and enhance their catalyst role in sustainability development. Previous literature acknowledges the tensions of emerging industries, however, the research has largely focused on the producer level, missing a holistic view of the supply chain and how it affects overall production efforts (Forbes and Kirsch, 2011). Moreover, the prior research on emerging industries has been mainly on the technical challenges of the companies, making the sustainability issues understudied, thus representing a gap in the literature.

This study addresses these aforementioned gaps by examining 14 companies with different supply chain positions working in the field of biobased plastics packaging, representing one of the emerging sectors within the sustainable packaging industry. This industry and the specific sector were selected as an exciting field for investigation due to its specific characteristics. Firstly, the industry aims to solve some of today's most significant and highly discussed sustainability issues: fossil oil dependency and the use of conventional plastics. Secondly, it is a new and developing industry open to changes and innovations. New types of biobased plastic packaging have been developed in the last 30 years, with the adaptation to the market still being in its infancy (Spierling et al., 2018). Hence, analyzing this industry can provide development guidance for other emerging innovative industries. Thirdly, although these products, made from renewable materials such as sugarcane, wood, and corn, are slowly becoming more widespread, there are many issues related to their product life cycles, and their commercial use is still low due to barriers in their application (Molina-Besch and Keszleri, 2023). Lastly, as biobased plastics may create unintended sustainability consequences such as environmental and social issues related to land use change during feedstock production, complicating waste management of other plastics (Turkcu et al., 2022), it is a challenging and controversial area. Biobased plastic packaging products are triggering discussions on different platforms (such as the academia, packaging industry, associations, and EU regulators) about their sustainability, what should be done to make them more sustainable, if they should be banned or limited further or promoted further.

In this study, we examine this interesting field by focusing on the following research questions: *What are the characteristics of the tensions of sustainable packaging production? How can companies manage such tensions in an emerging and innovative industry?*

The study's findings revealed 20 tension categories connected to sustainable packaging production (SPP) in an emerging industry, arising at the economic, structural, psychological, and behavioral levels and 12 different strategies for companies to manage such tensions. The most significant identified management strategies were linked to issues of creating an ecosystem, partnering, collecting waste, performing due diligence, advisory services, joining associations, localization, customer selection, business model innovation, innovation and research, having certificates, and communication. By identifying the companies' responses to managing different tension categories, this study discusses the possibilities of managing different types of tensions and conflicting situations that cannot be solved by companies on their own but require collaboration with various actors or support from the governmental level. The paper contributes especially to the growing literature on the unintended consequences of sustainable production and their management. Furthermore, the study contributes to the current literature on emerging industries by highlighting the sustainability perspective in studying challenges and management actions in these industries.

2. Literature review

2.1. Tensions of sustainability production

The production of sustainable products means ensuring the production of environmentally friendly, socially beneficial and economically viable products and services. This means considering the sustainable development goals, including their environmental, social, and economic dimensions throughout the life cycles of products and services (Maxwell and Van der Vorst, 2003). In sustainable production, potential unintended consequences may appear between actors due to different economic and social goals, especially when environmental and sustainability goals are involved (Reypens et al., 2016). This is because of the involvement of a more diverse and multi-layered set of actors and decision-makers (Baraldi et al., 2011) and a broader network(s) of stakeholders and supply chain partners (Meqdadi et al., 2017). Tensions can be defined as negative consequences, such as strain and conflict, that result from contradictory goals, motivations, and interests between different network actors (Hahn et al., 2015). Sustainable production may result in different types of tensions (economic, structural, psychological, and behavioral), as companies need to address interconnected and interdependent economic, environmental and social concerns of the production at different levels (Hahn et al., 2015). These tensions are perceived differently by different network actors (Fang et al., 2011; Tóth et al., 2018). For instance, economic tensions involve higher prices charged by customers due to the increased costs caused by the producer's sustainability efforts, decreased functionality, or information acquirement and dissemination costs due to the need for education on sustainable business practices (Tura et al., 2019). Usually, these relate to differences between an actor's value capture (the captured benefits) and appropriation logic (i.e., the activities and abilities to capture the created value) (Chou and Zolkiewski, 2018). Structural tensions refer to how inter-organizational relationships are organized and governed between stakeholders (Galati et al., 2021). These can include, for example, tensions related to increased dependence on key suppliers due to certain raw material requirements (Tura et al., 2019). Psychological tensions refer to cognitive aspects, such as the attitudes and perceptions of different actors (Slawinski and Pratima, 2015). These can relate to, for example, (mis)trust and temporal orientations and include financial risks perceived by producers due to the high uncertainty of consumer needs, commercialization potential and the long-term nature of potential benefits (Peltola et al., 2016). There is also potential for political risks due to constantly changing political decisions, regulations, and legislation considering sustainable development (Tura et al., 2019). Behavioral tensions refer to actors' activities, routines, and communicative practices (Fang et al., 2011; Tóth et al., 2018) and can include, for

example, increased communication and promotion needs for new sustainable products, their characteristics and end-of-life requirements, as well as clashing goals between different network actors.

Some of the possible tensions represent situations referred to as trade-offs, meaning "compromise situations when a sacrifice is made in one area to obtain benefits in another" (Byggeth and Hochschorner, 2006, p. 1420). In product development and procurement processes, these situations occur when there is a need to balance alternative solutions stressing different features (ibid.). In the corporate sustainability context, trade-offs describe situations where the economic, environmental, and social aspects of sustainability cannot be achieved simultaneously (Hahn et al., 2010). Thus, they are situations requiring compromises between sustainability goals that conflict with each other. Hence, in the management of trade-offs, the contradiction is eliminated by the decision of adopting one goal over another (Brix-Asala et al., 2018; Van der Byl and Slawinski, 2015).

2.2. From identification to the management of tensions

The CSR literature identifies two approaches to managing tensions (Siltaloppi et al., 2021; Van der Byl and Slawinski, 2015). The first approach is avoiding the tensions by prioritizing business targets (referring to trade-offs) or by seeking win-win situations so that selected CSR elements do not interfere with economic goals (de Jong and van der Meer, 2015; Van der Byl and Slawinski, 2015). The second approach is actively managing the tensions by embracing them and connecting them to a company's strive for deeper integration between social and economic targets, accepting tensions as an inherent part of sustainable business and balancing the tensions through different strategies (Gao and Bansal, 2013; Hahn et al., 2015).

Tension management is a topic that has been addressed by applying theories from paradox literature. In contradiction to the management of trade-offs of sustainability production (avoiding the possible tensions), according to paradox theories, sustainability tensions need to be embraced. When aiming to understand tensions from the paradox theory point of view, the goal is to understand the tensions, their nature, and how actors deal with them (Van der Byl and Slawinski, 2015). A paradoxical perspective enables decision-makers to achieve competing sustainability objectives simultaneously (Hahn et al., 2018). However, it requires identifying and understanding the nature of different tensions and how different actors perceive them. The coexistence of contradictory elements should be admitted (Smith and Lewis, 2011; Hahn et al., 2015), and by using different management strategies, the situations should then be changed in such a way that interrelating requirements can be pursued simultaneously without removing the tension (Brix-Asala et al., 2018).

Following the strategies for paradox management (Poole and van de Ven, 1989; Schad et al., 2016), tension management strategies can be divided into three categories: the acceptance strategy, the separation strategy (spatial and temporal), and the synthesis strategy. The first, *the acceptance strategy*, is about allowing the tension to remain. The tension is not ignored, but the company has identified a way to live with it (Schad et al., 2016). This approach is recognized as a catalyst for change and renewal (Graetz and Smith, 2009). The second, the *separation strategy*, can be divided into spatial and temporal separation. In spatial separation, different interests related to demands, processes, or perspectives are separated, e.g., to different levels, such as within organizational units, micro-macro, or individual vs. society levels (Poole and van de Ven, 1989). In temporal separation, the tensions are separated in time or place so that one side of the tension is favored at some point and another at a different point (Jarzabkowski et al., 2013). The third, *the synthesis strategy*, means applying new perspectives to manage the tension by introducing a new element that helps to accommodate both contradictory poles of the tension (Schad et al., 2016).

2.3. Managing the tensions in an emerging industry

Emerging industries are established due to the opportunities created by changes in technological possibilities, changing customer preferences or pressure by government policies, that work as triggers for innovation development, usually by new market entrants (Peltoniemi, 2011; Gong et al., 2022). Although emerging industries may bring multiple opportunities and possibilities especially for entrepreneurs, they are also connected to high uncertainty and challenges (Forbes and Kirsch, 2011; Gustafsson et al., 2016; Phall et al., 2011). The establishment of companies requires high initial investments (Horii, 2012) and problems may occur during the establishing of technology and production infrastructure (Moeen, 2017). Also, obtaining raw materials may be hampered due to the characteristics of available materials or lack of established suppliers (Porumboiu, 2020). In the beginning of the development of a new industry, information of products and industry participants is often limited and the demand is unclear. Due to the high technological uncertainty and lack of dominant design architecture (Gong et al., 2022) consumers of the goods do not have complete information of the products and need to learn more about them (Moeen et al., 2020), and as a result, the customers' willingness to pay for products may be low. As the rivalry increases and the quality of the product improves, possibly also lowering the price, the product becomes more valuable for customers growing the demand (Agarwal and Bayus, 2002). Although the industry grows, a lot of investment on the development, research and marketing of the products is needed together with simultaneous business process improvements (Moeen et al., 2020). Thus, in such young industries, the businesses may be unprofitable due to the expenses caused by development and the marketing of the offering compared to low revenues (Gersch et al., 2013; Moeen, 2017). Emerging industries are also characterized by multiple entries and exits, and organizations learn by observing the experiences of others and by incorporating practices and procedures that are perceived to be successful (Peltoniemi, 2011). An emerging industry usually also lacks legitimacy, which pushes the actors to engage in collective system-level actions (Gong et al., 2022), forming associations and identifying collectively constructed and industry-wide strategies towards government regulations. In such young industries, companies thus face the shared challenge of building the legitimacy of the emerging industry (Gao and McDonald, 2022). Although the prior literature acknowledges these challenges, and identifies some strategies to answering these challenges, the literature on tension management in the emerging industry context is scarce. Furthermore, although emerging industries are seen to be an important driver towards sustainable development, the management of sustainability tensions is missing.

In summary, the prior literature has, to some extent, aimed to increase the understanding of the various tensions linked to sustainable production practices and different strategies for their management. However, as Joseph et al. (2020) note, further research is required to understand the applicability and usefulness of tension management strategies. By addressing the tensions based on their characteristics (economic, structural, behavioral, and psychological), this study increases the understanding of how different management strategies are applicable in terms of different tensions in an emerging industry.

3. Methods

This study is an explorative, qualitative study of 14 companies across eight countries. The qualitative research approach was selected as the research methodology due to its suitability to generate deep and rich understanding of a research topic at its early stage (Corbin and Strauss, 2015) and to collect comprehensive and comparable information in a relatively short period of time. The study focuses on the biobased packaging industry, one of the exciting and developing areas of sustainable packaging production.

3.1. Data selection and collection

The data was gathered from 14 companies through in-depth semi-structured interviews. In-depth semi-structured interviews were used to understand the interviewees' perspective and diverse opinions in detail (Denzin and Lincoln, 2011; Kvale and Brinkmann, 2009). The selected companies represented one or more supply chain stages of the biobased plastics packaging product field, including monomer and polymer producers, converters, packaging producers, wholesalers, and end product users (brand owners) (see Fig. 1.). Including companies from different supply chain positions allowed the creation of a versatile view of the operations within the field. As the industry is emerging, the number of companies working in the sector is limited, and the existing companies are relatively small. To identify the companies in the market, several ways were used. The initial list of the companies was identified by a Google search using the keywords of "biobased plastic packaging companies", "biobased companies", "biobased plastic packaging sector" and "bioplastic companies". This was followed by the screening of Linkedin Groups (such as "Bioplastics: Compostable, Biodegradable & Biobased plastics", Biomass 4 Biobased Products", "BioBased Economy") and Association websites (such as "European Bioplastics e.V." and "Biodegradable Plastics Association") linked to the industry to identify further companies. Furthermore, the snowball sampling technique (Parker et al., 2019) was used to identify more informants and companies based on the suggestions of other informants. The information of the identified companies was collected to an excel sheet, including basic details about the company such as company's supply chain stage, size of the company and country of origin. Companies in the list were contacted by considering having a variety of companies working in different supply chain stages, countries and produced types of products. With a few cases from other countries to provide variety to the data, the companies operated primarily in the EU. Interviewees were selected based on their involvement and knowledge of the topic, preferring sustainability professionals and otherwise identifying the most knowledgeable person in the company. The interviewees were reached through e-mail or Linkedin messages and asked for a virtual meeting through Microsoft Teams.

The interviews were conducted in June–August 2022 and lasted between 30 and 80 min resulting in a total of 761 min of interview data. The semi-structured interviews were recorded and transcribed. The details of the interview data are provided in Table 1. An interview protocol with open-ended questions was created to structure the discussion while allowing the informants to express their ideas freely (Eisenhardt, 1989). Guiding interview questions can be found in the supplementary information (SI) section. The interviews started by asking questions related to the informants' knowledge of the sustainability issues of biobased plastics and sustainable packaging in general, related challenges, experiences of these from their company's perspective, and possible mitigation actions. To increase the reliability of the study (Creswell, 2006), the richness of the data, and to crosscheck the information provided by the interviewees, secondary data sources were added, including company websites, blog posts, and action-, sustainability- and annual reports.

3.2. Data analysis

The data analysis was done by content analysis methodology, which is a flexible method for large amounts of textual data (Cavanagh, 1997). The analysis was conducted by several researchers in order to minimize the impact of individual bias and thus increase the validity. The analysis followed the qualitative content analysis guidelines with data reduction, data display, drawing of conclusions, and verification (Miles and Huberman, 1994). The data reduction was made by NVivo 13 software, found to be a trustworthy and efficient software for going through transcripts (Bazeley and Jackson, 2013), and Excel spreadsheets.

The data analysis proceeded in three main stages. In the first stage, the textual data was analyzed by open coding to identify the impacts, problems, and challenges connected to SPP. At this stage, the initial findings revealed multiple conflicts and challenges related to such products (such as a small market with small volumes, lacking infrastructures for EOL, and challenges regarding materials in achieving durability). After individual coding, the researchers gathered to discuss the emerging themes and outcomes. This made it feasible to create an understanding regarding the different possible tensions connected to SPP, and how various supply chain parties perceived them. The second stage focused on analyzing the identified tensions and categorizing them based on their characteristics and properties (Corbin and Strauss, 2015). The findings were then compared to the existing literature on the challenges of SPP, the tensions of sustainable business practices, emerging industries and management strategies for said tensions. Based on this analysis, the tensions were grouped into specific themes and integrated into a framework (Table 2). At this stage, the data were also analyzed in terms of tension management strategies, and "management strategies" was marked as one of the emerging themes due to the informants' remarks and explanations of managing sustainability problems within their company. These were further divided into sub-sections such as "joining associations" or "business model innovation." The third stage concentrated on drawing conclusions and linking the results of the tensions and their management techniques.

4. Results

4.1. Experiencing the tensions of sustainable packaging production

The analysis revealed 20 tension categories related to SPP, emerging at the economic, structural, psychological, and behavioral levels that create conflict in the implementation and transition towards sustainable packaging production (Table 2). Within the tensions, there also exists different trade-off situations where there is a need to make compromises on one sustainability goal over another.

4.1.1. Economic tensions

Economic tensions included *high investment and operating costs*, as entry to the market requires high investments in technological development, infrastructure, management, innovation and testing; making it hard to enter and operate in the market. The production and distribution processes require a high amount of resources (such as electricity and water), causing *cost pressure*. Since the market for sustainable packaging products is relatively small, conflicting views exist about its *financial viability*. From the consumer perspective, the analysis revealed the tension of *higher or uncertain prices*, as producers were identified to charge higher prices from customers due to the costs of selecting sustainable materials and producing processes. Furthermore, as the technological development in the industry is not complete, sustainable packaging products deliver different functionality or performance than alternative

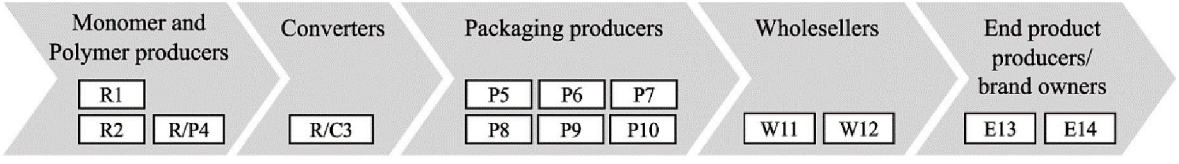

Fig. 1. Illustration of the interviewed companies and their supply chain positions.

Table 1
Data information.

No	Company	Country	Interviewee	Time of the interview	Duration
R1	Small-sized producer of compostable bottles	Netherlands Branch (US Based Company)	Sustainability Manager	11.07.2022	65 m
R2	Large-sized monomer producer	The Netherlands	Regulatory and Sustainability Manager	26.08.2022	68 m
R/C3	Small-sized producer of wood-based material	Finland	Sustainability and Communications Director	28.06.2022	56 m
R/P4	Small-sized producer of wood-based packaging	Finland	Director of Sustainability	13.07.2022	80 m
P5	Small-sized producer of PLA Bottles	European Branch (US Based Company)	Project Director	23.06.2022	70 m
P6	Large-sized producer of flexible packaging	Finland	Group Head of Brand and Sustainability	29.06.2022	31 m
P7	Large-sized producer of different kinds of packaging	European Branch (Japan Based Company)	International Business Development Manager Europe	29.06.2022	30 m
P8	Small-sized producer of flexible packaging	UK	CEO	01.07.2022	33 m
P9	Small-sized producer of compostable packaging	Germany	Commercial Director	14.07.2022	47 m
P10	Small-sized packaging producer	Germany	Chief Technical Officer	14.07.2022	62 m
W11	Small-sized seller of Single Use Plastics (SUP)s	The Netherlands	CEO	27.06.2022	60 m
W12	Mid-sized seller of SUPs	Australia	CEO	28.06.2022	56 m
E13	Mid-sized producer of food products	Switzerland	Packaging Development Manager	18.08.2022	48 m
E14	Small-sized producer of food products	Germany	Chief Operating Officer	31.08.2022	55 m

products such as plastics, causing the tension of *reduced functionality and performance*.

4.1.2. Structural tensions

Producers experienced difficulties in operation and determining the sustainability of their products due to *lacking standards and guidelines* to follow in production and EOL operations; making it hard for the producers to manage their operations. Also, customers were seen to be confused and have difficulties managing the EOL of the products without clear guidelines and standards; causing them to either utilize the wrong EOL option or prevent them from buying the products. Producers also have *difficulties balancing different management and operating activities* due to varying taxation policies between different product types and old and varying regulations between different areas. Divergent activities and rules that had to be follow were experienced to cause conflicts and problems as the producers do not know which rules to follow. In addition, within the industry, there were *difficulties in deciding who should participate in decision-making* concerning politics within the industry. This was also related to *conflicting views of the responsibilities* for changing the system, including infrastructural changes, land degradation, EOL operations, and setting standards and guidelines. This makes setting up the appropriate guidelines even harder. Furthermore, the tension of *difficulties in getting data and information about the origin of the raw materials* emerged between producers and raw material suppliers, causing conflicts in the sustainability measurement of the operations. This links to the problems of emerging markets regarding the low number of suppliers and no established tracking systems.

4.1.3. Psychological tensions

The central *psychological tensions* included *political risk* and *financial concerns*, which were strongly related. Due to being a new industry, laws and regulations evolve and change more often in comparison to mature industries. With the changing regulations, manufacturers face the political risk of investing and making the necessary changes in their production systems as the laws change, frequently making it difficult to predict the industry's future norms. Producers fear that changing political decisions and regulations may also negatively affect the market, and they experience the need to invest in extra activities and allocate extra resources to follow the varying regulations. Furthermore, producers worry that political decision-makers need more expertise and understanding to judge the markets of sustainable packaging. They fear that decision makers' lack of expertise would cause inappropriate regulations creating issues for producers.

In addition, the psychological tensions were also connected especially to customers. These included *greenwashing concerns*, i.e., consumers (or producers) having a fear of wrongful sustainability claims about products. The majority of the industry's businesses are small to medium-sized, and greenwashing was perceived as posing a danger of financial loss because of their shaky financial stability. This was also related to the customers' *conflicting beliefs about sustainability and fear of negative side effects*, causing concerns about the sustainability and safety of recycled products; possibly decreasing demand. Because the products are new, consumers have less knowledge about the products. Similarly, EOL operators also have less knowledge about the products in comparison to the established industries, making it hard to develop the necessary EOL operations. Operators fear the negative side-effects of integrating sustainably produced packaging products into their processes as they are worried about the contamination of their streams.

4.1.4. Behavioral tensions

Behavioral tensions were experienced by multiple levels of actors. The tension of the *extra need for education* was related to the government and producers' need to educate the consumers about the principles and EOL of the products and producers' need to educate the network actors providing EOL actions. This was highly related to the *conflicts between activities and processes*, i.e., conflicting views among actors within the industry about the suitable actions and behavior, for example, related to the most suitable and beneficial EOL scenarios. Furthermore, as the products and the market are new, producers need to put *extra effort into marketing and communicating* to the markets about the products and their characteristics. They also need to put *extra effort into activities and decisions regarding the supply of raw materials* as the industry is new, number of suppliers is also low; creating a supply problem.

Also, due to the lacking actions on collecting and recycling sustainable packaging products, the producers cannot find enough materials to be used as recycled raw materials, even though some companies have goals to increase their usage of recycled biobased plastic packaging. Also, *higher disclosure requirements* were experienced by producers as a need to put extra effort into checking and solving the concerns of customers. Behavioral tensions also concerned customers, especially due to *problematic design* of products as consumers have difficulties in differentiating the products (as they look like traditional plastics) in waste sorting and may thus prefer other packaging options.

There also exists trade-off situations that were connected to the

Table 2
Summary of the categories of the tensions related to SPP.

	Tension	Description
Economic tensions Conflicts between cost allocations.	High investment & operating costs	Entry to the market, production and distribution processes requires high investments.
	Costs of operational changes	Needed change on the current infrastructures and activities for the EOL of products requires resources.
	Small market with high financial uncertainty	The supply chain's companies have concerns about the financial viability of the small market.
	Higher or uncertain prices	Suppliers charge higher prices from the producer companies. The products' prices are not transparent or consistent across the market.
	Reduced functionality and performance	Sustainable packaging products do not deliver the same functionality or performance as conventional products.
Structural tensions The different ways organizational relationships are organized and governed within stakeholders.	Conflicting views of responsibilities	Conflicting views about the changes in infrastructure, EOL operations and standards.
	Lacking standards and general guidelines	Companies have difficulties in operation and determining the sustainability of their products. Customers find it challenging to manage a product's EOL.
	Difficulties to balance government activities and policies	Producers have difficulties in balancing their activities due to varying taxation policies and regulations within and between countries.
	Difficulties to decide who should participate in decision making	Contradictory perspectives about industry decision-making.
	Difficulties in getting data and information about the origin of raw materials	Producers are conflicted about the sustainability measurement of their operations.
Psychological tensions Cognitive aspects, such as attitudes and perceptions of different actors.	Political risk	Producers fear that changing regulations will negatively affect the market and that the decision makers lack the necessary expertise.
	Financial risk	Producers fear making investments due to high political risk making it hard to guess the future of the market.
	Greenwashing concerns	Consumers fear that producers make wrongful sustainability claims of the products.
	Conflicting beliefs about the sustainability and fear of negative side-effects	Consumers and EOL operators have concerns and fears.
Behavioral tensions Actors' activities, routines and communicative practices.	Need for extra effort on education	Government and producers need to educate the network actors on EOL and product characteristics.
	Conflicts between activities and processes	Conflicting views among actors about the suitable actions and behavior.
	Need for extra communication and marketing actions	Producers need to put extra effort on marketing and communicating about their products.
	Need for extra efforts on supply	Producers need to put effort on activities and decisions regarding supply of raw materials.
	Higher disclosure requirements	Producers need to put effort on checking and solving the concerns of customers.
	Problematic design	Consumers have difficulties in waste sorting and may thus prefer other packaging options.

required compromises between different sustainability outcomes, industry and technological uncertainty, and conflicts between short and long-term goals, which are linked to the aforementioned tensions. For example, currently, the production of the products within the industry still requires decisions/outcomes that are not very sustainable such as the usage of hazardous materials and the high amounts of electricity and water use during production, creating high investment & operational costs. Furthermore, the industry must cope with conflicting economic, environmental, and social outcomes, including other undesirable ecological effects. For instance, although the raw materials are renewable and more sustainable than fossil-based materials, they must be transported long distances creating logistics emissions and costs. Thus, companies need to put extra effort into considering the impact of their decisions regarding the supply of raw materials.

4.2. Managing the tensions of sustainable packaging production

The analysis of the tension management strategies revealed different actions that companies are executing to accept, lower, or actively manage conflicting situations. Active management strategies are executed through the following separation and synthesis strategies (Schad et al., 2016). These included the creation of an ecosystem, partnering, collecting waste, performing due diligence, advisory services, joining associations, localization, customer selection, business model innovation, innovation and research, having certificates, and communication.

In terms of managing the *economic tensions* coming from the cost of operational changes at the EOL level, and waste management companies being unwilling to accept these products in their systems, most companies have adopted the acceptance strategy and accepted that they do not have the power to deal with such tensions. Furthermore, government assistance is seen necessary as the present corporate solutions can only address EOL issues on a modest scale. However, some companies still decided to work on solutions such as applying a *synthesis strategy* by *collecting and recycling the waste* in their own facilities. Some companies chose to follow *spatial separation strategies* to tackle EOL problems by partnering with different companies (such as mobile composters) or *innovating* their own compost machine, bringing the infrastructure to their customers' kitchens so that they do not have to deal with industrial composters. Another identified strategy was the *creation of an ecosystem* for recycling by gathering all the stakeholders together. In accordance with the characteristics of emerging industries, innovations in business processes, products, and research and development activities are seen to

be key operations.

In order to tackle the *structural tension* of lacking standards and general guidelines, most of the companies have adopted a spatial separation strategy by *joining associations* such as the European Bioplastics Association and EU consultations which would advocate for improving standards and guidelines on a higher level. These companies chose to address the tensions affecting their companies at a larger systemic level, aiming to tackle the *behavioral tension* of the need for extra education. Moreover, these associations also help to tackle the *structural tension* of the problem of conflicting views of responsibilities as they aim to gather all the responsible parties and create consensus on decision making. In the same way, the structural tension of lacking standards and general guidelines is also aimed to be tackled by pushing the government and regulatory bodies through the associations, collective system-level actions and collectively constructed and industry-wide strategies, as also noted by emerging industry literature. In order to manage the *structural tensions* of difficulties in getting data and information about the origin of raw materials and lowering the risk of negative sustainability impacts, some companies have adopted a *synthesis strategy* by *localization* and chose suppliers only from Europe to increase transparency and control on sustainability issues. Due to the same reason, one company was planning to move a part of its production operations to Europe, aiming to simultaneously decrease transportation costs and tackle *economic tensions*. In order to avoid the *psychological tension* of greenwashing risks, one company chose to *perform due diligence* on their customer company to check if they promote the correct EOL strategy. Similarly, a consumer product producer provided an *advisory service* for their retailers to promote the correct EOL services in the countries the products are sold, adopting a synthesis strategy. Another packaging producer company chose to implement *customer selection* and not work with certain customers whose values do not align with their own, adopting a *spatial separation strategy*. In order to tackle the *psychological tension* of fear of negative side effects composters have, one company chose to reach out to the relevant composters and educate them about this fear through effective *communication*. These investments in education are in line with the need of putting extra effort on communication actions due to the lower knowledge of the products and their characteristics among the consumers and other actors within the industry. As business in the emerging industries evolves and companies learn from others, business model changes are not rare. Some companies chose to *innovate their business model* to tackle tensions by adopting a *synthesis strategy*. For example, one producer company created a nongovernmental organization (NGO) that helps customers (restaurants) with their EOL problems to manage the *behavioral tension* of the need for extra effort on education. One company created a specific business model providing only a recipe for the products without any manufacturing plants to tackle the *economic tension* of high investment costs for entering the market. Another company built a business model around working with customers with closed-loop systems such as conferences, airlines, and cruise lines that have control over collecting their own waste.

In order to tackle *the behavioral tension* of having higher disclosure requirements and extra education and communication needs, companies invested in *innovation and research*. Some companies chose to fund the research of different institutions or invest in their innovation and research actions, conducting carbon footprint and life-cycle-assessment (LCA) calculations and adopting a *synthesis strategy* for higher disclosure requirements. For similar reasons, companies chose *to have certificates* about raw materials, sourcing, and appropriate composting options with the aim communicating better with customers. Apart from the management strategies explained above, companies also described situations where they could not work around the tension and compromises were inevitable. They needed to make compromises regarding trade-offs, mostly about favoring environmental concerns over financial concerns. One company claimed to use fewer chemicals, while another planned to donate a portion of its profits to various environmental projects. One company mentioned making an extra effort to manage its internal waste with a more costly recycling technique. Some companies mentioned making high financial investments to innovate new products, for instance, that can dissolve in water or can be produced without agriculture. Furthermore, one company mentioned working on utilizing recycled biobased material they collected themselves or bought from recyclers in order to increase their sustainability efforts; even though these materials would be significantly more costly.

5. Discussion

The identified economic tensions were experienced especially by the producer companies. As the industry is new, production processes still need to be optimized, and the companies working in the area have limited financial resources. This result is not surprising as it is typical in the emerging industries (Porumboiu, 2020). EOL management was another area expressed by the interviewees to significantly create cost pressure. To manage the EOL of the items, the industry also needs to make considerable adjustments to its infrastructure and operations. As the current EOL infrastructure is mostly built for the conventional plastics industry, a need for adjustments in infrastructure occurs when biobased plastics enter the market as a substitute. These adjustments are expensive and demand resources, which may cause them to impede other activities. As the performance is lower, brand owners also expressed hesitation to use them for their products and may prefer less sustainable options with higher performance. Overall, economic tensions were expressed by the companies regardless of their supply chain stage, country of origin and size.

As a solution to these economic tensions, two solution ideas were offered requiring significant government intervention. Subsidizing products' production and providing extra economic support by the government, were seen essential to make the industry profitable. Moreover, allocating government funds to EOL infrastructure development was raised as a significant solution strategy. As in many emerging industries, SPP is conducted in small volumes, increasing the price of the materials. By lowering manufacturing costs and hence raising product quantities, the price of the materials may be lowered. However, volumes can only be increased if a large-scale, functional EOL infrastructure exists. At the same time, infrastructure can only be developed if it is economically possible, which can only occur when there are large volumes of products, creating a paradox that is hard to solve. Companies' efforts can help to solve certain issues but not the major ones, such as the previously discussed financial viability issue. Similar to the findings from Kakadelli and Harris (2020) and Spierling et al. (2018), government support is required to increase the availability of these items, particularly in the form of investments in infrastructure management for EOL operations, consistency of the collection and infrastructure between municipalities and support for waste management companies, which will enable the products to be used more widely and at lower costs. A different approach to lowering the price and hence increasing volumes is to incentivize the products. Additionally, mandating some biobased packaging items where it makes the most sense (such as tea bags and coffee capsules) might assist in boosting volume and, in turn, decrease prices.

As the producer companies see government intervention in the management of economic tensions, many of the structural tensions were naturally identified to emerge between producers (industry) and governments. As the industry is still in a development stage, the responsibility of the decision making remains unclear, and laws, regulations, taxation policies and guidelines about production, processes and EOL are identified to be missing. All the parties expressed that the lobbying power of conventional plastics is likely to play a role in strengthening the structural tensions. It was believed by the interviewees that the dominance of plastic packaging players in local, national and international governments prevents politicians from gaining the necessary knowledge to make appropriate decisions in favor of BPP. The dominant discourse in favor of recycling conventional plastics

id believed to affect not only the policy makers but also the public opinion and consumers' knowledge about the products and the appropriate EOL behavior. This situation was seen as the main reason for the psychological and behavioral tensions. Even though companies try to solve these tensions, government intervention is seen as the best solution. It is observed that the companies expressed that they do not blame the customers for their lack of knowledge even though they acknowledged it is a big issue. The general consensus was that customers are willing to adapt if they can be provided with appropriate information and infrastructure by the government. To spread the correct knowledge about these products' possible benefits and use, SPP companies have focused on certain strategies to have more influence on government and policy making. Being a member of associations and combining forces with other businesses or NGOs were viewed as strategies to increase one's ability to influence government authorities and bring about structural and systemic changes. In such young industries as the biobased plastic packaging industry, it was no surprise this was stated as one of the most commonly executed management strategies by the interviewed companies.

Making extra effort in research and communication activities helps to increase the companies' understanding of their products and ensure that they can accurately inform consumers is another common strategy used by the companies to tackle tensions. Besides expending high communication efforts to legitimize their products, companies in emerging industries tend to prioritize innovation and they are willing to pay for it. As a result, focusing on innovation is one of the main strategies companies have been adopting. The main incentive of emerging industries is satisfying customers' demands, and economic incentives are usually not the priority. Companies in emerging industries commonly have less flexibility in their operations because they typically do not have the financial means. However, if they see a chance to make their operation more sustainable, they are willing to sacrifice a certain amount of their profit. Hence, even though economic tensions were often underlined, companies were aware that they cannot mitigate these tensions for now. This shows their commitment to sustainability. It is possibly a characteristic of the sustainable packaging industry that differs from other emerging industries which do not have a focus on sustainability.

Identifying and understanding the different tensions is an essential first step to managing the effects of said tensions (Van der Byl and Slawinski, 2015) and thus lowering the possibility of the negative effects of sustainable production. The significance of being aware of tensions and looking for solutions was also highlighted by most of the study's informants. Solutions were applied regardless of the company's size, country of origin, or supply chain stage. However, several reported tensions were believed to be heavily dependent on governmental actions or were accepted as characteristics of an emerging industry, which is why these tensions were also accepted as a part of the sector.

In contrast to the study by Joseph et al. (2020), the findings revealed multiple tensions, representing situations that companies just accepted. These include, for example, the economic tension of a small market with high financial uncertainty and higher and uncertain prices, as solving these in the short run would require systemic changes and a high governmental role. Similarly, some structural tensions, like difficulties in balancing government activities and policies, were mainly accepted by the companies as they require solutions from the governmental side, such as having a standardized policy and taxation strategies. The reduced functionality and performance of the products was also a tension that the companies accepted, possibly because the solutions would require time and high innovation and research investments, and technological uncertainty and development were seen as a natural part of the operations. As in many new innovative industries, achieving a high level of functionality for products takes time. In the long run, as the quality of the product improves, consumers begin to understand the value of the product, possibly increasing demand. Also, the increasing rivalry within the market will lower prices and may guide companies to adopt new strategies. However, this will take time.

Some tension management strategies, like customer selection, can be done without making compromises to the point that they still can attract enough clients to support their business financially; if there are enough customers or if supply is within demand. Similarly, localization in manufacturing can only be done if the local businesses are likewise profitable. These situations are usually associated with the required investments, increasing management expenses, and lower (short-term) economic performance due to the selected management activities. Companies must decide whether to prioritize economic business targets or, for instance, address EOL challenges by investing in waste collection. Thus, the division between possible manageable tensions and trade-offs that require compromises is vague and often is often dependent on how the companies frame them. Acknowledging the interconnectedness and interdependence of sustainability tensions would help companies to find solutions to them (Hahn et al., 2015, 2018).

5.1. Key contributions

The study contributes to the emerging literature on the dark side of sustainability focusing on the tensions of sustainable production (Joseph et al., 2020; Tura et al., 2019). By providing empirical insights from 14 companies in an emerging industry, this study answers the call for empirical research on the unintended consequences of sustainable production and their management (see, e.g., Brix-Asala et al., 2018; Sundqvist-Andberg and Åkerman, 2021). Along with the study by Zehendner et al. (2021), this study is among the few studies on the dark side of sustainability, and the first study in the field of biobased plastics packaging, offering empirical insights of different types of tensions experienced within the emerging and developing industry of SPP. By combining insights from marketing literature on various types of tensions (e.g., Tóth et al., 2018) and the tension management strategies identified in CSR literature (e.g., Siltaloppi et al., 2021; Hahn et al., 2015) and paradox management theories (e.g., Van der Byl and Slawinski, 2015; Schad et al., 2016), this study identifies how different types of tensions are and could be managed, as well as the circumstances in which businesses' individual efforts are insufficient.

This study highlights that the tensions do appear not only on the corporate level but also at the industrial and societal levels, requiring extra consideration of the possible management actions. Although the literature is pushing companies towards extended producer responsibility and designing products with EOL considerations (Campbell-Johnston et al., 2020), the responsibilities and roles of governmental decision-making, such as building and harmonizing the infrastructures for EOL operations, developing and harmonizing the regulations should also be highlighted.

From the managerial perspective, this study can benefit companies considering getting into this specific industry or those operating in other emerging industries. Being aware of the forthcoming sustainability tensions, companies can prepare themselves for the problems ahead and come up with solutions in advance. This can decrease the exit rates of companies from the market while hopefully increasing the entries resulting in the faster development of the emerging industry.

5.2. Limitations and future research

This study includes companies from various supply chain stages and empirical examples from inside and outside the EU. However, more examples, particularly outside of the EU, could improve the richness of the data and the generalizability of the conclusions. Moreover, further research investigating the tensions and management strategies to these tensions depending on the company size would be an interesting avenue for research. A complete picture of the causes of the tensions and potential future management strategies that companies are unaware of might be achieved by incorporating different stakeholders, including government representatives, waste management companies, and

citizens/consumers. Studying other types of sustainable packaging products in the future is strongly advised to highlight the slight variations in packaging types, their sustainability challenges, as well as the potential development directions of the market, even though studying the biobased plastic packaging sector of the sustainable packaging industry undoubtedly increases knowledge about the sustainability challenges of SPP in general. Furthermore, comparing the study results with another sustainable production industry would make an interesting research avenue, especially to study the tension management strategies and their applicability in different contexts. Similarly, comparing the results of this study with a developed industry and some other emerging industries in terms of their barriers and management strategies, empirically pointing out the more detailed similarities and differences would create interesting discussions. Also, one of the most highlighted and interesting findings of this study is the formation of strategic groups to tackle several tensions. Elaborating on these findings in the context of sustainable emerging industries, taking the perspective of collaboration in comparison to competition would be an interesting avenue of research. Studying the types of these collaborations, as well as the reasons and limits to them would be relevant and timely. Moreover, as the research provides a relatively static perspective on tensions and their management, an interesting avenue for future study would be to employ a longitudinal research setting and investigate the effects in the long run.

6. Conclusions

This study examined the different tensions arising from sustainable packaging production and how the economic, structural, psychological, and behavioral tensions are managed by companies working in the industry. This study demonstrates that companies of any size or supply chain stage may employ tension management strategies. As a result, it shows that even the companies in emerging industries are able to employ tension-management strategies and find creative solutions to their sustainability-related challenges without making significant compromises.

According to the study findings, economic tensions are found to be more challenging to manage as they require systemic and market changes. Hence the companies mostly accept the economic tensions and prioritized sustainability efforts. To manage structural, behavioral, and psychological tensions, government support is highly needed to develop and harmonize the collection and EOL management infrastructure, incentivize both production and EOL, increase and harmonize regulations within different regions and countries, and improve labeling and standards. After creating the necessary EOL infrastructure, making biobased plastic packaging mandatory for certain products, such as coffee and tea capsules, would be an effective solution to help develop this industry and fight plastic waste in general. Furthermore, to spread knowledge about the products and gain support from the government, partnering (e.g., with NGOs) and joining associations was seen as an effective strategy to manage certain tensions. Therefore, these might represent the minimal cost and effort of initial steps by companies in emerging industries to grow their power. Combining forces with other groups, including those within the business as well as outside parties, could be a powerful instrument for managing tensions. In general, as the industry is still growing and still being legitimized, paying extra attention to communication is suggested. Conducting LCAs, increasing supply chain visibility, gaining certificates, and having customer advisory services would help gain trust from the consumers and government and improve the correct use and disposal of these products.

In general, this study aims to help make the fundamental shift of thought from sustainable production systems being inheritably good to having many sustainability challenges. By identifying these challenges, defined as tensions, and their characteristics, this study helps to increase the understanding of sustainable packaging production and its so-called dark side. This study also identifies possible strategies to manage these tensions and provides tools and examples for companies in the emerging industries to increase their products' long-term environmental, financial and social benefits.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2023.07.007.

References

Agarwal, R., Bayus, B.L., 2002. The market evolution and sales takeoff of product innovations. Manag. Sci. 48, 1024–1041.
Baraldi, E., Gregori, G.L., Perna, A., 2011. Network evolution and the embedding of complex technical solutions: the case of the Leaf House network. Ind. Mark. Manag. 40 (6), 838–852.
Bazeley, P., Jackson, K., 2013. Qualitative Data Analysis With NVivo, Second edition. SAGE Publications Ltd, London. ISBN: 978-1-4462-5655-8.
Brix-Asala, C., Geisbüsch, A.K., Sauer, P.C., Schöpflin, P., Zehendner, A., 2018. Sustainability tensions in supply chains: a case study of paradoxes and their management. Sustainability 10 (2), 424.
Byggeth, S., Hochschorner, E., 2006. Handling trade-offs in ecodesign tools for sustainable product development and procurement. J. Clean. Prod. 14 (15–16), 1420–1430.
Campbell-Johnston, K., Friant, M.C., Thapa, K., Lakerveld, D., Vermeulen, J.V., W., 2020. How circular is your tyre: experiences with extended producer responsibility from a circular economy perspective. J. Clean. Prod. 14 (15–16), 270, 122042.
Cavanagh, S., 1997. Content analysis: concepts, methods and applications. Nurse Res. 4 (3), 5–16.
Chen, M.S., Eweje, G., Kennedy, J.C., 2021. Managerial sensemaking of tensions in sustainability: empirical evidence from Chinese and New Zealand business partnerships. J. Clean. Prod. 319, 128699.
Chou, H.H., Zolkiewski, J., 2018. Coopetition and value creation and appropriation: the role of interdependencies, tensions and harmony. Ind. Mark. Manag. 70, 25–33.
Corbin, J., Strauss, A., 2015. Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory, 4th ed. Sage, Newbury Park, CA.
Creswell, J.W., 2006. Qualitative Inquiry & Research Design: Choosing Among Five Approaches. Sage.
Denzin, N.K., Lincoln, Y.S., 2011. The SAGE Handbook of Qualitative Research. Sage, London, UK.
Diggle, A., Walker, T.R., 2020. Implementation of harmonized extended producer responsibility strategies to incentivize recovery of single-use plastic packaging waste in Canada. Waste Manag. 110, 20–23.
Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manag. Rev. 14 (4), 532–550.
Fang, S.R., Chang, Y.S., Peng, Y.C., 2011. Dark side of relationships: a tensions-based view. Ind. Mark. Manag. 40 (5), 774–784.
Ferreira-Filipe, D.A., Paço, A., Duarte, A.C., Rocha-Santos, T., Patrício Silva, A.L., 2021. Are biobased plastics green alternatives? A critical review. Int. J. Environ. Res. Public Health 18 (15), 7729.
Forbes, D.P., Kirsch, D.A., 2011. The study of emerging industries: recognizing and responding to some central problems. J. Bus. Ventur. 26, 589–602.
Galati, F., Bigliardi, B., Galati, R., Petroni, G., 2021. Managing structural inter-organizational tensions in complex product systems projects: lessons from the Metis case. J. Bus. Res. 129, 723–735.
Gao, C., McDonald, R., 2022. Shaping nascent industries: innovation strategy and regulatory uncertainty in personal genomics. Adm. Sci. Q. 67 (4), 915–967.
Gao, J., Bansal, P., 2013. Instrumental and integrative logics in business sustainability. J. Bus. Ethics 112 (2), 241–255.
Gerassimidou, S., Martin, O.V., Chapman, S.P., Hahladakis, J.N., Iacovidou, E., 2021. Development of an integrated sustainability matrix to depict challenges and trade-offs of introducing bio-based plastics in the food packaging value chain. J. Clean. Prod. 286, 125378.
Gersch, M., Rüsike, T., Reichle, F., 2013. Competence building in electric mobility: solving the paradox of specific investments in nascent industries. Int. J. Automot. Technol. Manag. 13 (3), 273–288.
Gong, H., Binz, C., Hassink, R., Trippl, M., 2022. Emerging industries: institutions, legitimacy and system-level agency. Reg. Stud. 56 (4), 523–535.

Govindan, K., Shaw, M., Majumdar, A., 2021. Social sustainability tensions in multi-tier supply chain: a systematic literature review towards conceptual framework development. J. Clean. Prod. 279, 123075.
Graetz, F., Smith, A.C.T., 2009. Duality theory and organizing forms in change management. J. Chang. Manag. 9 (1), 9–25.
Gustafsson, R., Jääskeläinen, M., Maula, M., Uotila, J., 2016. Emergence of industries: a review and future directions. Int. J. Manag. Rev. 18, 28–50.
Gustavo Jr., J.U., Pereira, G.M., Bond, A.J., Viegas, C.V., Borchardt, M., 2018. Drivers, opportunities and barriers for a retailer in the pursuit of more sustainable packaging redesign. J. Clean. Prod. 187, 18–28.
Hahn, T., Figge, F., Pinkse, J., Preuss, L., 2010. Trade-offs in corporate sustainability: you can't have your cake and eat it. Bus. Strateg. Environ. 19 (4), 217–229.
Hahn, T., Pinkse, J., Preuss, L., Figge, F., 2015. Tensions in corporate sustainability: towards an integrative framework. J. Bus. Ethics 127 (2), 297–316.
Hahn, T., Figge, F., Pinkse, J., Preuss, L., 2018. A paradox perspective on corporate sustainability: descriptive, instrumental, and normative aspects. J. Bus. Ethics 148 (2), 235–248.
Horii, R., 2012. Wants and past knowledge: growth cycles with emerging industries. J. Econ. Dynam. Control 36, 220–238.
Jarzabkowski, P., Lê, K.J., van de Ven, A.H., 2013. Responding to competing strategic demands: how organizing, belonging, and performing paradoxes coevolve. Strateg. Organ. 11 (3), 245–280.
Jestratijevic, I., Maystorovich, I., Vrabič-Brodnjak, U., 2022. The 7 Rs sustainable packaging framework: systematic review of sustainable packaging solutions in the apparel and footwear industry. Sustain. Prod. Consump. 30, 331–340.
de Jong, M.D.T., van der Meer, M., 2015. How does it fit? Exploring the congruence between organizations and their corporate social responsibility (CSR) activities. J. Bus. Ethics 143 (1), 71–83.
Joseph, J., Borland, H., Orlitzky, M., Lindgreen, A., 2020. Seeing versus doing: how businesses manage tensions in pursuit of sustainability. J. Bus. Ethics 164 (2), 349–370.
Kakadelli, S., Harris, Z.M., 2020. Don't scrap the waste: the need for broader system boundaries in bioplastic food packaging life-cycle assessment — a critical review. J. Clean. Prod. 274.
Kvale, S., Brinkmann, S., 2009. Interviews: Learning the Craft of Qualitative Research Interviewing. Sage, London, UK.
Longo, C., Shankar, A., Nuttall, P., 2019. "It's not easy living a sustainable lifestyle": how greater knowledge leads to dilemmas, tensions and paralysis. J. Bus. Ethics 154 (3), 759–779.
Maxwell, D., Van der Vorst, R., 2003. Developing sustainable products and services. J. Clean. Prod. 11 (8), 883–895.
Meherishi, L., Narayana, S.A., Ranjani, K.S., 2019. Sustainable packaging for supply chain management in the circular economy: a review. J. Clean. Prod. 237, 117582.
Meqdadi, O., Johnsen, T.E., Johnsen, R.E., 2017. The role of power and trust in spreading sustainability initiatives across supply networks: a case study in the bio-chemical industry. Ind. Mark. Manag. 62, 61–76.
Miles, M.B., Huberman, A.M., 1994. Qualitative Data Analysis: An Expanded Source Book, 2nd edition. California, Thousand Oaks, Sage.
Moeen, M., 2017. Entry into nascent industries: disentangling a firm's capability portfolio at the time of investment versus market entry. Strateg. Manag. J. 38 (10), 1986–2004.
Moeen, M., Agarwal, R., Shah, S.K., 2020. Building industries by building knowledge: uncertainty reduction over industry milestones. Strat. Sci. 5 (3), 218–244.
Molina-Besch, K., Keszleri, H., 2023. Exploring the industrial perspective on biobased plastics in food packaging applications — insights from Sweden. Sustain. Prod. Consumpt. 35, 72–84.
Nordin, N., Selke, S., 2010. Social aspect of sustainable packaging. Packag. Technol. Sci. 23 (6), 317–326.
Pålsson, H., Sandberg, E., 2020. Paradoxes in supply chains: a conceptual framework for packed products. Int. J. Log. Manag. 31 (3), 423–442.
Pålsson, H., Sandberg, E., 2021. Packaging paradoxes in food supply chains: exploring characteristics, underlying reasons and management strategies. Int. J. Phys. Distrib. Log. Manag. 52 (11), 25–52.
Parker, C., Scott, S., Geddes, A., 2019. Snowball Sampling. SAGE Research Methods Foundation. https://doi.org/10.4135/9781526421036831710.
Peltola, T., Aarikka-Stenroos, L., Viana, E., Mäkinen, S., 2016. Value capture in business ecosystems for municipal solid waste management: comparison between two local environments. J. Clean. Prod. 137, 1270–1279.
Peltoniemi, M., 2011. Reviewing industry life-cycle theory: avenues for future research. Int. J. Manag. Rev. 13 (4), 349–375.
Phall, R., O'Sullivan, E., Routley, M., Ford, S., Probert, D., 2011. A framework for mapping industrial emergence. Technol. Forecast. Soc. Change 78, 217–230.
Phelan, A.A., Meissner, K., Humphrey, J., Ross, H., 2022. Plastic pollution and packaging: corporate commitments and actions from the food and beverage sector. J. Clean. Prod. 331, 129827.
Poole, M.S., van de Ven, A., 1989. Using paradox to build management and organizational theory. Acad. Manag. Rev. 14, 562–578.
Porumboiu, C., 2020. The importance of emerging industries: the case of biopharma. In: Eurasian Economic Perspectives: Proceedings of the 28th Eurasia Business and Economics Society Conference. Springer International Publishing, pp. 3–12.
Reypens, C., Lievens, A., Blazevic, V., 2016. Leveraging value in multi-stakeholder innovation networks: a process framework for value co-creation and capture. Ind. Mark. Manag. 56, 40–50.
Schad, J., Bansal, P., 2018. Seeing the forest and the trees: how a systems perspective informs paradox research. J. Manag. Stud. 55 (8), 1490–1506.
Schad, J., Lewis, M.W., Raisch, S., Smith, W.K., 2016. Paradox research in management science: looking back to move forward. Acad. Manag. 10 (1), 5–64.
Siltaloppi, J., Rajala, R., Hietala, H., 2021. Integrating CSR with business strategy: a tension management perspective. J. Bus. Ethics 174 (3), 507–527.
Slawinski, N., Pratima, B., 2015. Short on time: intertemporal tensions in business sustainability. Org. Sci. (Providence, R.I.) 26 (2), 531–549.
Smith, W.K., Lewis, M.W., 2011. Toward a theory of paradox: a dynamic equilibrium model of organizing. Acad. Manag. Rev. 36 (2), 381–403.
Spierling, S., Knüpffer, E., Behnsen, H., Mudersbach, M., Krieg, H., Springer, S., Albrecht, S., Herrmann, C., Endres, H.-J., 2018. Bio-based plastics — a review of environmental, social and economic impact assessments. J. Clean. Prod. 185, 476–491.
Sundqvist-Andberg, H., Åkerman, M., 2021. Sustainability governance and contested plastic food packaging—an integrative review. J. Clean. Prod. 306, 127111.
Tóth, Z., Peters, L.D., Pressey, A., Johnston, W.J., 2018. Tension in a value co-creation context: a network case study. Ind. Mark. Manag. 70, 34–45.
Tura, N., Keränen, J., Patala, S., 2019. The darker side of sustainability: tensions from sustainable business practices in business networks. Ind. Mark. Manag. 77, 221–231.
Turkcu, D., Tura, N., Ojanen, V., 2022. A conceptual framework of the sustainability challenges experienced during the life cycle of biobased packaging products. Sustainability 14.
Van der Byl, A., Slawinski, N., 2015. Embracing tensions in corporate sustainability: a review of research from win-wins and trade-offs to paradoxes and beyond. Organ. Environ. 28, 54–79.
Zehendner, A.G., Sauer, P.C., Schöpflin, P., Kähkönen, A.K., Seuring, S., 2021. Paradoxical tensions in sustainable supply chain management: insights from the electronics multi-tier supply chain context. Int. J. Oper. Prod. Manag. 41 (6), 882–907.

Publication III

Turkcu, D., and Tura, N.
The role of end-of-life lock-ins in the diffusion of eco-innovations

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Publication IV

Turkcu, D., and Levänen, J.
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