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Reference Model for Product Development in the Plastic Packaging Sector Focused on the Circular Economy

Paulo Henrique Paulista

Advisor: Prof. Dr. Carlos Henrique Pereira Mello

Co-Advisor: Profa. Dra. Jeniffer de Nadae

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Advisor: Prof. Dr. Carlos H. P. Mello
Co-advisor: Profa. Dra. Jeniffer de Nadae

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Examination Board:

Prof. Carlos Henrique Pereira Mello, Ph.D. (Advisor)
Prof. Jeniffer de Nadae, Ph.D. (Co-advisor)
Prof. Juliana Helena Daroz Gaudencio, Ph.D. (Internal Reviewer)
Prof. Carlos Eduardo Sanches da Silva, Ph.D. (Internal Reviewer)
Prof. Graziela Darla Araujo Galvão, Ph.D. (External Reviewer)
Prof. Rosinei Batista Ribeiro, Ph.D. (External Reviewer)

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Dedication

I dedicate this achievement to my beloved wife Elizângela, who is always by my side, giving me strength and helping me; to my parents Renato and Imaculada for their support; to my siblings Renato and Gleice for their encouragement; and to all my family members for their trust in me.

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Resumo

A grande maioria das empresas atualmente opera em um sistema de economia linear, no qual a produção, o consumo e o descarte são os pilares fundamentais de seus modelos de negócios. Esse sistema tradicional frequentemente não leva em consideração a regeneração de recursos. No entanto, a economia circular surge como uma abordagem revolucionária, desafiando esse paradigma. A economia circular é um modelo econômico que prioriza a sustentabilidade, com o objetivo principal de minimizar o desperdício e promover a reutilização, reciclagem e regeneração de recursos naturais. A essência dessa abordagem consiste em criar um ciclo contínuo, onde produtos, materiais e recursos são mantidos em uso pelo maior tempo possível, prolongando suas vidas úteis. Diante desse cenário de transição para a economia circular, as empresas enfrentam o desafio de reformular seus processos de desenvolvimento de produtos, uma vez que os produtos necessitam nascer circulares. Tal desafio se torna ainda mais relevante no setor de embalagens, em especial no segmento de embalagens plásticas, caracterizado pelo elevado consumo de materiais virgens, pela curta vida útil funcional dos produtos e pelos significativos impactos ambientais associados ao descarte inadequado. Cada setor industrial, seja têxtil, médico, automotivo, eletrônico ou outros, possui suas peculiaridades e particularidades nos processos de inovação de produtos. No entanto, muitas vezes, esses processos não integram eficazmente os princípios da economia circular. Nesse contexto, esta tese propõe um modelo para o desenvolvimento de produtos no setor de embalagens plásticas, estruturado a partir da integração sistemática dos conceitos da economia circular ao processo de desenvolvimento de produtos. O ponto de partida foi um estudo abrangente dos princípios da economia circular e das práticas de desenvolvimento de produtos para, assim, propor um modelo que integre esses conceitos. A fim de validar a eficácia do modelo proposto, o estudo de caso foi o procedimento metodológico selecionado, sendo analisadas duas empresas do setor de embalagens plásticas selecionadas com base em critérios previamente definidos para assegurar a representatividade do segmento. A coleta de dados foi realizada por meio de um questionário estruturado, elaborado especificamente para captar informações relacionadas às práticas de economia circular ao longo das diferentes etapas do processo de desenvolvimento de produtos. A análise dos casos permitiu avaliar o grau de incorporação dos princípios circulares nas empresas estudadas, bem como identificar convergências, limitações e oportunidades de aprimoramento do modelo proposto. O principal resultado da pesquisa consiste na proposição de um modelo de desenvolvimento de produtos com foco na economia circular, fundamentado no modelo *Stage-Gate* de Cooper, adaptado às especificidades do setor de embalagens plásticas, o qual evidencia que a circularidade não pode ser incorporada de forma tardia ou pontual, mas deve ser concebida desde as fases iniciais do desenvolvimento, reforçando que um produto verdadeiramente circular precisa ser pensado, planejado e estruturado desde o seu início para maximizar o desempenho ambiental, técnico e econômico ao longo de todo o seu ciclo de vida.

Palavras-chave: Economia Circular; Processo de Desenvolvimento de Produto; Produtos Circulares; Stage-gate.

Abstract

The vast majority of companies currently operate within a linear economy framework, where production, consumption, and disposal constitute the fundamental pillars of their business models. This traditional system frequently overlooks resource regeneration. Conversely, the circular economy emerges as an approach that challenges this paradigm by prioritizing sustainability, waste reduction, and the retention of products, materials, and resources in use for as long as possible. Facing this transition toward a circular economy, companies are challenged to redesign their product development processes, as products must be "born circular." This challenge becomes particularly relevant in the plastic packaging sector, which is characterized by high consumption of virgin materials, short functional product lifespans, and significant environmental impacts associated with improper disposal. Although various industrial sectors present specific product development process models, many of these frameworks still do not systematically integrate Circular Economy principles. In this context, this thesis proposes and validates a reference model for plastic packaging development focused on the circular economy, structured around Cooper's Stage-Gate logic and integrated with Circular Economy practices, tools, and criteria throughout the Product Development Process (PDP). The model operationalizes circularity within the PDP by incorporating decisions related to material reduction, the use of post-consumer recycled (PCR) content, design for recycling, reuse, disassembly, traceability, reverse logistics, and post-launch indicators. The development of the model was grounded in a comprehensive study of circular economy principles and product development practices. To validate its suitability and applicability, a case study methodology was adopted, analyzing two companies within the plastic packaging sector selected based on predefined criteria to ensure segment representativeness. Data collection was conducted through a structured questionnaire, specifically designed to capture information regarding circular economy practices across the different stages of the product development process. The cross-case analysis allowed for an assessment of the degree to which circular economy principles are incorporated within the studied companies, identifying convergences, limitations, and opportunities for improvement, as well as verifying the adherence of the proposed model to the analyzed industrial context. The results demonstrate that circularity cannot be integrated late or in an ad-hoc manner; rather, it must be conceived from the early stages of development. As its main scientific and applied contribution, this thesis presents a validated reference model for the development of circular plastic packaging, helping to bridge the gap between the conceptual principles of the Circular Economy and their practical operationalization within the Product Development Process.

Keywords: Circular Economy; Product Development Process; Circular Products; Stage-gate.

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List of Abbreviations

3R – Reduction, Reuse, and Recycling
ABRE – Brazilian Packaging Association
LCA – Life Cycle Assessment
BOPP – Biaxially Oriented Polypropylene
CFD – Circular Function Deployment
DFX – Design for X
CE – Circular Economy
IE – Industrial Ecology
NCE Strategy – National Circular Economy Strategy
EPR – Extended Producer Responsibility
EU – European Union
FMEA – Failure Mode and Effects Analysis
GHG – Greenhouse Gases
IoT – Internet of Things
RIL – Recycling Incentive Law
SDGs – Sustainable Development Goals
UN – United Nations
PCR – Post-Consumer Recycled
PE – Polyethylene
PET – Polyethylene Terephthalate
PDP – Product Development Process
GDP – Gross Domestic Product
NCEP – National Circular Economy Policy
PNRS – National Solid Waste Policy
PP – Polypropylene
PVC – Polyvinyl Chloride
QFD – Quality Function Deployment
PSS – Product–Service System
SWOT – Strengths, Weaknesses, Opportunities, and Threats

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1. Introduction

1.1 Research Context

According to Assunção (2019), several economic sectors have been discussing environmental issues and actions aimed at reducing the environmental impacts caused by companies.

Considering environmental pressures and the scarcity of raw materials, there has been a growing interest in the circular economy among industrial, political, and academic communities (Dias, 2019; Mulgan, 2015; Nguyen, Stuchtey, & Zils, 2014).
It can be argued that the main difference between the linear economy and the circular economy is that, in the former, natural resources are used in a disorderly manner without considering their scarcity. In contrast, in the circular economy, what is discarded is reused by the next system (Assunção, 2019).

The circular economy suggests that resources should be used intelligently so that extracted and produced materials remain in circulation, enabling the creation of integrated production chains. Thus, the destination of a material is no longer merely a matter of waste management, but it becomes part of the product and system development process (Sehnem & Pereira, 2019; Webster, 2015).

With the advancement of sustainability, the United Nations (UN) established the 2030 Agenda and the Sustainable Development Goals (SDGs) in 2015. The 2030 Agenda is a global declaration of commitments adopted to implement 17 goals and 169 targets by 2030, aiming to support actions in areas that are crucial to human life (João, 2022).

According to João (2022), the following SDGs present characteristics related to the circular economy: (ii) Zero Hunger and Sustainable Agriculture, (iii) Good Health and Well-Being, (vi) Clean Water and Sanitation, (vii) Affordable and Clean Energy, (viii) Decent Work and Economic Growth, (ix) Industry, Innovation and Infrastructure, (x) Reduced Inequalities, (xi) Sustainable Cities and Communities, (xii) Responsible Consumption and Production, (xiii) Climate Action, and (xvii) Partnerships for the Goals.

In addition to the circular economy, it is necessary to consider the product development process so that all these concepts can be aligned and harmonized.

There is extensive research addressing the product development process, and many models have been developed to meet the needs of different industrial sectors. Thus, these models are specific to particular industrial fields. Examples include models developed for the textile industry (Rodrigues, 2016), packaging (Oliveira et al., 2018), the steel industry (Souza, Amaral, & Melo Filho, 2020), and healthcare equipment (Lobato et al., 2019).

When analyzing these models, which propose production and consumption systems, it can be observed that they do not address resource scarcity nor the reuse of products after disposal, as suggested by the circular economy.

Therefore, incorporating the circular economy into the product development process becomes necessary so that concerns regarding resource scarcity are addressed and all products, components, and materials maintain a high level of utility and value at all times.

One sector that deserves analysis involving these two concepts is the packaging sector. Packaging is one of the most common—and possibly one of the most neglected—items in the current economic model, as its functionality is quickly lost. Once the goods it contains are removed or consumed, packaging is generally perceived as a nuisance to be discarded. When disposed of after a single use, it immediately loses 95% of the economic value of its material (Souza, 2021).

Zhu et al. (2022) emphasize that the packaging industry plays a significant economic role and is essential to the economy, with a notable growth rate each year. In Western Europe, the turnover of this industry represents approximately 2% of GDP (Gross Domestic Product), with the food industry being the main consumer, absorbing nearly 60% of total packaging production. The use of packaging permeates virtually all aspects of everyday life.

According to Firouz, Mohi-Alden, and Omid (2021), the field of food packaging is experiencing rapid growth due to global population growth and continuously improving food safety regulations. Packaging plays a crucial role in preserving and maintaining the quality of food products for export, storage, and final consumption. A company in the United States forecasts that by 2024 the packaging market revenue will reach approximately US$6 billion for one specific type and nearly US$3.45 billion for another type of packaging.

The global packaging market generates more than US$500 billion. In Brazil, this sector generates BRL 144.4 billion, according to 2023 data from the Brazilian

Packaging Association (ABRE, 2024). Due to the quality requirements in manufacturing, the packaging sector is the largest consumer of virgin materials. In Europe, 40% of the plastic and 50% of the paper produced are used for packaging (Nascimento, 2022).

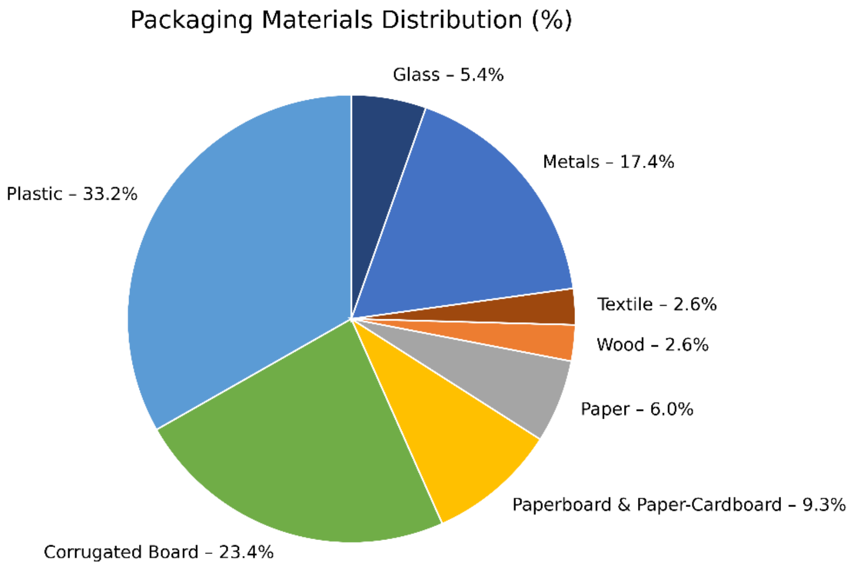

Figure 1: Distribution of the Gross Production Value of Packaging
Source: ABRE (2024)

The Brazilian Packaging Association (ABRE, 2024) produced a chart showing the distribution of the gross production value of packaging by segments, considering data from 2023, as shown in Figure 1.

In 2018, global plastic production reached 359 million tons, but only about one-third was recycled in Europe. PET (polyethylene terephthalate) degrades very slowly in nature and can remain for up to 2,000 years. Due to this environmental concern, alternative packaging materials continue to be explored (Holler et al., 2023).

According to Testa et al. (2021), a study revealed that in 2019 approximately 6.2 million tons of plastic, mainly from municipal solid waste, and about 3.0 million tons of microplastics, such as rubber from worn tires, were introduced into the global environment in 2015, with the majority originating from packaging. The "European Strategy for Plastics in a Circular Economy" seeks to urgently address the environmental problems associated with plastic production, use, and consumption. It establishes targets such as recycling at least 55% of all plastic packaging in the European Union by 2025. These guidelines have been implemented nationally through laws encouraging recycling and the use of bio-based polymers, while discouraging the use of disposable plastic packaging.

Nascimento (2022) states that regarding the growing accumulation of waste, plastic production alone had already reached 8.3 billion tons by 2017. According to the report of the first global analysis on plastic production, if projections are confirmed, the accumulation of plastic waste may reach 12 billion tons by 2050.

In 2014, packaging waste generated in European households and various industries totaled approximately 82.5 million metric tons per year, while in the United States, 69.6 million metric tons of packaging waste were collected as part of municipal solid waste. In the European Union, 65.5% of this waste was recycled, whereas in the United States the recycling rate was 51.5% (Geueke, Groh, & Muncke, 2018).

Marco (2021) highlights that in Brazil it is estimated that one-fifth of the waste produced consists of packaging, totaling about 25 thousand tons per day. Most of this packaging is improperly disposed of, without undergoing recycling or reuse, which results in the depletion of landfills and dumps, hinders the degradation of other waste, pollutes the landscape, and causes several other negative consequences.

Packaging should be developed using renewable raw materials, kept in use for as long as possible, and, at the end of its life cycle, contribute to the regeneration of natural systems. The main challenge for designers is to ensure that packaging fulfills its functions satisfactorily for all stakeholders involved, from the product to the end user and the industry, focusing on sustainable solutions that do not harm the environment. The concept of sustainable development implies meeting present needs without compromising the resources of future generations, which is directly related to minimizing the environmental impact of packaging (Sastre, 2022).

The transition to renewable energy can eliminate 55% of global greenhouse gas emissions, but the remaining 45%, originating from sectors such as land management and the production of various everyday goods, represent more complex challenges. Notably, the adoption of bottle design innovations and refill models in areas such as beauty, personal care, and household cleaning for plastic packaging could reduce greenhouse gas emissions related to packaging and transportation by 80–85% compared to the use of disposable bottles (Ellen MacArthur Foundation, 2019).

According to the Ellen MacArthur Foundation (2015), the adoption of reusable glass bottles could result in a 20% reduction in costs associated with packaging, processing, and beer distribution.

Given the ongoing environmental degradation attributed to the increasing volume of packaging waste, there is a growing call for more robust approaches, requiring that packaging be designed, produced, consumed, and recycled in a more sustainable manner (Zhu et al., 2022).

Considering the current importance of packaging and the consequences of its improper disposal, it is essential to analyze its product development process.

1.2 Justification

There are several studies addressing product development models applied in different sectors of the economy. Some examples of these models have been analyzed to understand the contexts in which the PDP (Product Development Process) was applied.

Rodrigues (2016) presents in his research a conceptual model of the product development process in the textile industry. In this study, several methodological proposals for textile development were analyzed, and information was collected from companies in this sector through questionnaires and field observations. This approach enabled an understanding of the practices involved in textile product development. By comparing the data obtained with theoretical models, it was possible to propose a model. The proposed model was validated through an intervention in an industry, where improvements in the performance of the product development process were verified. Thus, this research presented a conceptual product development model that supports all the phases necessary for industrial practice, with a focus on the textile sector (Rodrigues, 2016).

The research conducted by Sonego (2018) uses the strategy of modularity in product development, highlighting purposes such as the generation of variety, economies of scale, reduction of assembly and production time, flexibility in the reuse of components, and ease of assembly and disassembly. The study analyzes the realization of the benefits of modularity while considering sustainability throughout the product life cycle. The benefits of modularity were observed in the use and disposal phases of electronic products, considering repair and the destination of products at the end of their life cycle. It was noted that design changes in product architecture aimed at sustainability are important but do not guarantee sustainability; therefore, it is essential to plan a system that enables and encourages the realization of the benefits envisioned during product development (Sonego, 2018).

Oliveira et al. (2018) conducted a study presenting a proposal for the development of aluminum foil packaging equipped with a movable cutting mechanism and user protection. Tools and techniques for decision-making in product development processes were used, such as QFD (Quality Function Deployment), Cost Analysis, FMEA (Failure Mode and Effects Analysis), Benchmarking, SWOT (Strengths, Weaknesses, Opportunities, and Threats), and Ergonomic Analysis. Thus, the format of this proposal sought to provide consumers with greater convenience, safety, and precision when cutting aluminum foil (Oliveira et al., 2018).

A multiple case study was conducted to analyze the product development process (PDP) in small and medium-sized technology-based companies. Through the analysis of company documents, interviews with PDP managers, and real-time observations, it was possible to identify characteristics that influence PDPs, such as investment, company founding date, and ISO 9001 certification (Salgado et al., 2018).

Morini (2019) conducted research analyzing product development and the evaluation of its life cycle with a focus on sustainability. A software tool was developed to assess the environmental load of a product in the early stages of its development. Embodied energy and carbon footprint were considered as evaluation metrics. The software was validated by comparing its results with the literature. With the aid of this tool, those involved in product development can select materials and processes with lower environmental impact (Morini, 2019).

Lobato et al. (2019) conducted a study analyzing product development in the field of medical equipment. A product development model was proposed that encompasses the main Brazilian regulations. Through a multiple case study, the model was presented to three medical device companies in order to compare their processes with the proposed model. Therefore, the study demonstrated the potential of using best practices as a guide for the development of processes in the healthcare equipment sector (Lobato et al., 2019).

A methodology for the new product development process in a service company operating in the sharpening and refurbishment of industrial cutting tools was presented. This methodology aims to facilitate the development of new services, based on a case study of the development process of a service: the sharpening of a 2000 mm saw for a large company in the steel industry (Souza, Amaral, & Melo Filho, 2020).

Diaz, Reyes, and Baumgartner (2022), Joustra et al. (2022), Ko (2020), and Lin (2018) emphasize that it is important to consider the CE (Circular Economy) in the PDP in order to optimize the use of scarce resources and ensure that products, components, and materials are utilized at their highest value at all times.

João, Maceno, and Antonelo (2025) conducted a study aimed at proposing a product development model guided by the principles of the Circular Economy (CE), with a specific focus on the packaging sector, seeking to systematically integrate circular practices into the traditional product development process. The proposed model, called the Circular Product Development Model, was developed by adapting the reference model of Rozenfeld, recognized for its comprehensiveness and applicability. Circular economy guidelines, strategies, and practices identified through a systematic literature review were incorporated into this model. Structured into three phases (pre-development, development, and post-development), the model includes two application flows: one oriented toward innovation, which incorporates Design Thinking tools from the early stages, and another focused on custom product development, a common characteristic of the packaging industry. In both flows, the model guides the definition of circular goals, the selection of sustainable materials, design for reuse, recycling and remanufacturing, life cycle assessment, the planning of more efficient production processes, and the proper management of the product's end-of-life.

As a form of validation, the same authors applied the model in a case study conducted in a company from the packaging sector, which allowed them to map its product development process and compare it with the theoretical proposal. The results showed that, although the company already adopts some practices aligned with the circular economy, these occur in a sporadic and poorly structured manner, indicating significant potential for incorporating additional practices throughout the process. The main outcome of the study lies in demonstrating that the proposed model is compatible with industrial reality, presents a high degree of adaptability, and contributes to the formalization and expansion of circular practices in packaging development, especially when adopted from the early stages, where decisions with the greatest environmental, technical, and economic impact throughout the product life cycle are concentrated.

The model proposed by João, Maceno, and Antonelo (2025) differs from the model presented in this thesis, which is based on Cooper's Stage-Gate reference model. It also differs in focus, since the model developed in this thesis is oriented toward plastic packaging, whereas the model proposed by João, Maceno, and Antonelo (2025) addresses packaging in general.

By analyzing these studies, it can be observed that there is extensive research in the field of the product development process (PDP), with each study presenting a particular method to meet the needs of a specific segment of the industrial sector. However, only a few models incorporate the circular economy into the PDP to enable better use of resources. Therefore, this gap needs to be addressed through a model that integrates the circular economy into the PDP.

The primary contribution of this thesis lies in the proposition and empirical validation of a reference model for plastic packaging development, structured around Stage-Gate logic and integrated with Circular Economy practices, tools, and criteria. Unlike the models identified in the literature, the proposed framework operationalizes circularity principles within the Product Development Process (PDP) through the systematic incorporation of decisions related to material reduction, the use of post-consumer recycled (PCR) content, design for recycling, disassembly, reuse, traceability, reverse logistics, and post-launch indicators. Consequently, this thesis contributes to narrowing the gap between the conceptual principles of the Circular Economy and their practical application in the industrial development of plastic packaging.

This thesis argues that in order to implement a circular business model, it is necessary to develop circular products. To achieve circular products, it is essential to have a PDP that incorporates the concepts of the Circular Economy (CE). The following authors reinforce this idea in their studies: BSI (2017), Dumée (2022), Ellen MacArthur Foundation (2019), Ghisellini, Cialani, and Ulgiati (2016), Hobson (2016), Khan and Haleem (2021), and Khan et al. (2021).

1.3 Research Question

Considering the gaps identified in the literature regarding the integration of the Circular Economy and the Product Development Process within the packaging sector, this thesis seeks to answer the following research question:
“How can Circular Economy principles and practices be integrated into the Product Development Process within the plastic packaging sector through a reference model?”

1.4 Objectives

1.4.1 General Objective

To propose and verify the suitability of a reference model for plastic packaging development, integrating Circular Economy principles, practices, and tools into the Product Development Process (PDP).

1.4.2 Specific Objectives

- To analyze circular economy (CE) practices and incorporate them into the product development process (PDP);
- To analyze the tools to be used in the PDP that integrate CE practices;
- To verify the suitability of the proposed reference model through a case study.

1.5 Thesis Delimitations

This thesis presents delimitations regarding the theoretical, sector-specific, and methodological scope adopted in the research.

In sector-specific terms, the study focuses exclusively on the plastic packaging sector, excluding other segments of the packaging industry or alternative industrial sectors. This delimitation was established due to the environmental relevance associated with plastic packaging, the complexity of challenges related to material circularity, and the need for an in-depth investigation of CE practices applied to the PDP in this specific context.

From a conceptual perspective, the research restricts the CE approach primarily to strategies related to material circularity, focusing on material reduction practices, reuse, recyclability, the use of post-consumer recycled (PCR) content, value recovery, and reverse logistics. Consequently, this study does not aim to broadly address all circular business models or all economic, social, and regulatory dimensions associated with CE.

Regarding the product development scope, the thesis concentrates on the incorporation of CE principles and practices into the PDP, without comprehensively covering the entire post-consumer chain, waste recovery, and systemic management of the circular supply chain.

In methodological terms, the research was developed based on the analysis of two case studies conducted within Brazilian companies in the plastic packaging sector. Furthermore, data collection was predominantly concentrated on professionals directly involved in product development, without transversally encompassing other organizational areas such as production, procurement, quality, logistics, and post-consumer operations.

Another research delimitation refers to the absence of a longitudinal implementation of the proposed model, which precludes quantitative comparative analyses regarding organizational performance before and after its practical application. Thus, the verification of the model focused on its theoretical suitability and adherence to the analyzed industrial context.

Additionally, the research did not include organizations with varying levels of CE maturity, as the analyzed cases exhibited relatively similar characteristics regarding the adoption of circular practices. Therefore, the proposed model does not incorporate specific mechanisms to measure or classify the degree of organizational CE maturity.

These delimitations do not invalidate the results obtained; rather, they define the specific context within which the analyses, propositions, and conclusions of this thesis must be interpreted.

1.6 Structure of the Thesis

This material, prepared for the doctoral qualification, is structured as follows:

- Chapter 1 presents an introduction to the proposed topic, outlining the objective and the justification for conducting the study;
- Chapter 2 addresses the theoretical background, presenting important concepts related to the circular economy and product development; Chapter 3 presents the proposed product development method that incorporates circular economy concepts;

- Chapter 4 describes the methodology used in the development of the thesis;

  Chapter 5 presents the case study conducted in two companies that manufacture plastic packaging;
- Chapter 6 presents the proposed model, its activities at each stage, and the verification of its adequacy;
- Chapter 7, the final chapter, concludes the thesis by demonstrating how the objectives were addressed and achieved.

2. Theoretical Background

This chapter presents key concepts related to the Circular Economy (CE) and the Product Development Process (PDP). Regarding the circular economy, definitions, principles, indicators, benefits, and barriers are discussed. Concerning the Product Development Process, definitions, models, the concept of circular products, and business models (SPS) are presented.

2.1 Circular Economy

Several authors, including Dias (2019), Sehnem and Pereira (2019), and Assunção (2019), emphasize that discussions on the Circular Economy (CE) are related to the publication of the article *The Economics of the Coming Spaceship Earth*, by the American evolutionary economist Kenneth Boulding. This article was presented at the Forum on the Future and Environmental Quality in a Growing Economy, held in Washington in 1966.

Ghisellini, Cialani, and Ulgiati (2016) state that the concept of the Circular Economy (CE) is related to different schools of thought. Pearce and Turner (1990) argue that the traditional or linear economy was proposed under the assumption that the environment is an inexhaustible source of resources. These authors also used the concept proposed by Kenneth Boulding in 1966 and discussed the principles of thermodynamic laws (energy conservation and entropy) in order to propose the economy as a closed circular system with virtually no exchange of materials with the external environment. Therefore, the circular economy is seen as a prerequisite for sustainability and for maintaining human life on planet Earth (Pearce & Turner, 1990).

The Circular Economy is based on some concepts from Industrial Ecology (IE), which seeks to relate industry and the environment in order to find solutions to minimize the impacts that industries have caused to the environment. Thus, the CE adopts some IE concepts to analyze and optimize industrial systems, aiming to establish a new model of economic development, production, distribution, and product recovery. In this way, processes and products are redesigned to maximize the value of resources while decoupling economic growth from the reckless use of resources (Lung & Levrat, 2014).

Figure 2 presents the evolution of economic thinking by considering three major milestones: the Linear Economy, Industrial Ecology, and the Circular Economy. Considering innovation in products and services incorporating ecological thinking, the economic model of industries and organizations has progressed through the exploratory, restorative, cyclical, and regenerative phases, which is the phase in which current thinking is concentrated (Sandoval, Jaca, & Ormazabal, 2018).

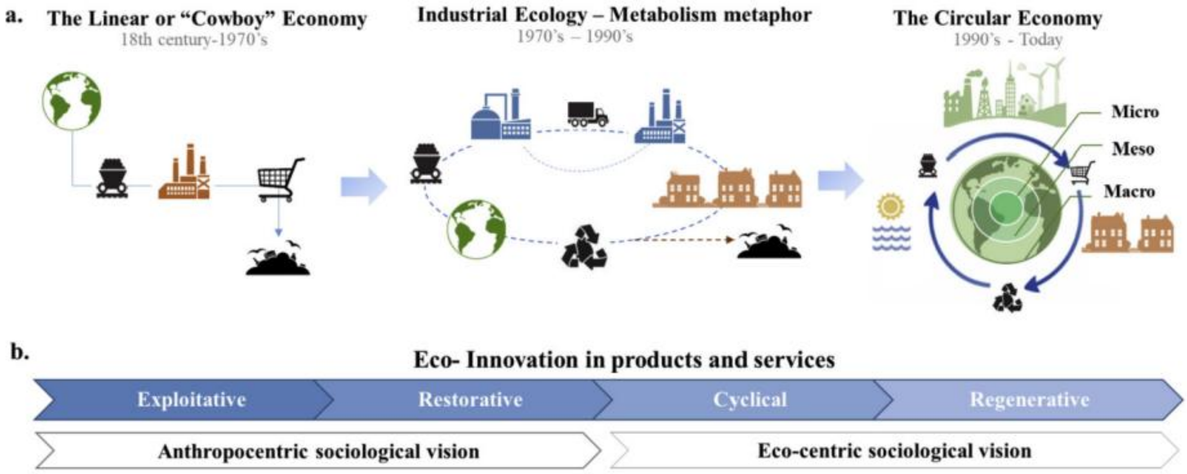

Figure 2: Evolution of Circular Economy Thinking
Source: Sandoval, Jaca e Ormazabal (2018)

Sandoval, Jaca, and Ormazabal (2018) state that the concept of the Circular Economy (CE) was developed through different disciplinary approaches such as ecology, economics, engineering, design, and business, which means that it emerged from a multidisciplinary perspective. The path that society has followed toward the CE can be divided into three major stages (Figure 2):

1. The first stage is the linear economy, which began with the Industrial Revolution and the overexploitation of resources. This phase was interrupted in the 1960s by a notable increase in environmental awareness, especially due to publications by ecologists, such as the book *Silent Spring* by Carson in 1962, and by economists such as Boulding in 1966, who postulated that planet Earth could function as an ecological system, recirculating limited resources and making them effectively unlimited.
2. The second stage began with the emergence of the first theoretical and practical initiatives of Industrial Ecology, founded by Ayres and Kneese in 1969 and later expanded by Ayres in 1989. These authors explained that industrial activities could function as a metabolism in which different actors are integrated through their waste and resources, which continuously circulate within the system's resource inventory. During this stage, interest

in a greener economy emerged. A green economy is defined by the United Nations Environment Programme as one that results in improved human well-being and social equity while significantly reducing environmental risks and ecological scarcity.

3. Finally, the third stage began in the early 1990s when Pearce and Turner (1990), following Boulding's research, introduced the term Circular Economy to explain the feasibility of incorporating environmental awareness into economic flows by closing industrial loops (Sandoval, Jaca, & Ormazabal, 2018).

The concept of the green economy has played a fundamental role in the environmental strategies of governments and institutions, but it tends to be associated with simple sustainability actions and fewer adaptations to people's lifestyles. In addition, these simple sustainability actions assume that economic benefits can substitute for human and natural capital, and they do not aim to achieve deep transformations in the linear system of production and consumption (Loiseau et al., 2016).

Sandoval, Jaca, and Ormazabal (2018) emphasize that the Circular Economy requires innovations in the way industries produce, consumers use products, and policymakers legislate. In this context, environmental innovation, or eco-innovation, has evolved over time alongside the Circular Economy. The evolution of eco-innovation was theorized by Hofstra and Huisingh (2014), who explain that there has been a sociological shift from an anthropocentric view of nature to an ecology-centered view. This shift has influenced how society evolves and develops environmental innovations, as illustrated in Figure 2.

Hofstra and Huisingh (2014) present four types of eco-innovation: exploratory, restorative, cyclical, and regenerative. The first two are associated with an anthropocentric sociological view of the world, where human needs are prioritized and the idea of growth derives from the traditional linear economy without considering limits to energy and material consumption (Figure 2). Exploratory eco-innovations pay little attention to environmental issues but comply with legal requirements and seek cost reductions. Restorative eco-innovations tend to develop solutions to repair damage that has already occurred, meaning they are corrective innovations. They are also eco-efficient in minimizing resource use and emissions. The other two types of eco-innovations, cyclical and regenerative, arise from the more recent ecology-centered sociological perspective, in which the ecosphere becomes important and humans are seen as part of nature rather than its owners, as presented in Figure 2. Cyclical eco-innovations connect humans and nature with the ecosystem to a greater extent and improve the capacity of systems to close loops. Finally, regenerative eco-innovations are closely related to the ecosystem's ability to create added value for both humans and nature. Consequently, humans must consider the role of their actions in the resilience of nature as human needs continue to grow.

Several authors have attempted to define the Circular Economy, and some of these definitions will be discussed in the next section.

2.1.1 Definitions of the Circular Economy

Ellen MacArthur Foundation (2013) and Webster (2015) define the Circular Economy (CE) as an economy that is restorative and regenerative by design, aiming to keep products, components, and materials at their highest level of utility and value at all times.

The CE seeks to achieve optimal production by simultaneously minimizing the use of natural resources and the emission of pollutants, promoting minimal waste through the reuse of production residues and minimal pollution through the recycling and restoration of technically unusable waste (Wu et al., 2014).

Ma et al. (2014) state that the CE is a mode of economic development aimed at protecting the environment and preventing pollution, thereby facilitating sustainable economic development.

The term circular economy is a generic term referring to activities of reduction, reuse, and recycling carried out in the processes of production, circulation, and consumption (Naustdalslid, 2014).

The CE is specifically based on resource efficiency and eco-efficiency, and its objective is to establish a set of key measures to advance toward a more circular, green, and sustainable economy (Ma et al., 2015).

Haas et al. (2015) emphasize that the CE is a compelling strategy aimed at reducing both the input of virgin materials and the generation of waste by closing the economic and ecological loops of resource flows.

The Circular Economy (CE) can be defined as an industrial system design that is restorative or regenerative. It replaces the concept of end-of-life with restoration, promotes the use of renewable energy, eliminates the use of toxic chemicals that hinder reuse and return to the biosphere, and aims to eliminate waste through the design of materials, products, systems, and business models (Hobson, 2016).

Singh and Ordonez (2016) state that the CE is an economic strategy that proposes innovative ways to transform the current predominantly linear consumption system into a circular one, while achieving economic sustainability together with the much-needed savings in materials.

A circular economy can be described as a restorative and regenerative design that aims to maintain products, components, and materials at their highest utility and value at all times. The concept represents a continuous positive development cycle that preserves and enhances natural capital, optimizes resource yields, and minimizes system risks by managing finite stocks and renewable flows (Moreau et al., 2017).

Niero et al. (2017) define the CE as an industrial system design intended to be restorative or regenerative.

Haupt, Vadenbo, and Hellweg (2017) emphasize that the CE can be conceptualized as a production and consumption system with minimal losses of materials and energy through extensive reuse, recycling, and recovery.

The CE is a general term that encompasses all activities that reduce, reuse, and recycle materials in production, distribution, and consumption processes (Blomsma & Brennan, 2017).

According to BSI (2017), the CE is an economy that is restorative and regenerative by design, aiming to maintain products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.

Stahel (2016) and Sandoval, Jaca, and Ormazabal (2018) state that the CE is generally described as a cycle of resource extraction and transformation followed by distribution, use, and recovery of goods and materials, as illustrated in Figure 2. First, companies extract resources from the environment to transform them into products and services. Next, they distribute these products or services to consumers at points of sale or to other companies, and the products/services are used by consumers in the market. At this stage, the CE proposes closing the loop through the recovery of goods instead of discarding or simply wasting them (Figure 3).

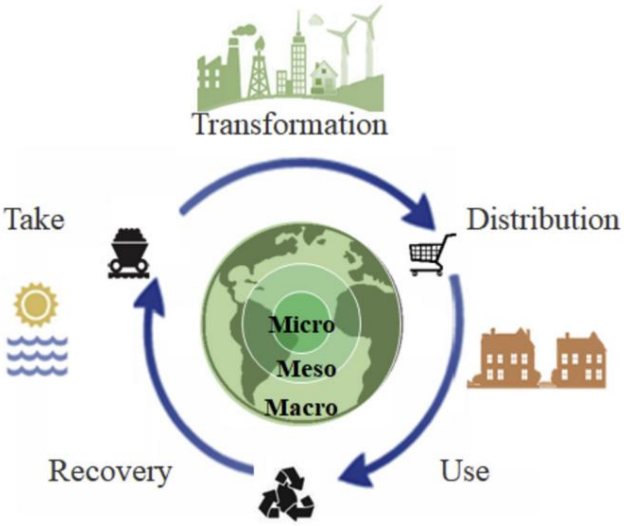

Figure 3: Circular Economy Cycle
Source: Sandoval, Jaca e Ormazabal (2018)

Sandoval, Jaca, and Ormazabal (2018) emphasize that four relevant components are necessary to establish the concept of the Circular Economy (CE):

- The recirculation of resources and energy, the minimization of resource demand, and the recovery of value from waste;
- A multilevel approach;
- Its importance as a pathway to achieving sustainable development;
- Its close relationship with the way society innovates.

The CE is an economic system that represents a paradigm shift in how human society relates to nature. It aims to avoid resource depletion, close energy and material loops, and facilitate sustainable development through its implementation at the micro (companies and consumers), meso (economic agents integrated through symbiosis), and macro (cities, regions, and governments) levels. Achieving this circular model requires cyclical and regenerative environmental innovations in the way society legislates, produces, and consumes (Sandoval, Jaca, & Ormazabal, 2018).

Heyes et al. (2018) and Rajput and Singh (2019) highlight that the objective of the CE is to improve resource efficiency and environmental performance at different levels of the supply chain.

The CE can also be understood as a closed-loop supply chain that focuses on restorative and regenerative aspects. It proposes that industrial systems integrate end-of-life concepts with restoration, eliminating the use of toxic materials and promoting reuse while reducing waste through the explicit implementation of design models, product systems, and material design (Rajput & Singh, 2019).

Jabbour et al. (2019), Hopkinson et al. (2018), and Esposito, Tse, and Soufani (2018) state that the CE is a production and consumption system that aims to keep products, components, materials, and energy in circulation in order to continuously add, recreate, and maintain their value over a long period of time. The CE is restorative, regenerative, and disruptive to traditional economic systems and therefore involves changes in design and production structures.

The CE can also be defined as a sustainable development initiative aimed at reducing the linear flows of materials and energy within society's production–consumption systems by applying material cycles and renewable energy flows. The circular economy promotes high-value material cycles along with more traditional recycling and develops systemic approaches for cooperation among producers, consumers, and other social actors in the pursuit of sustainable development (Korhonen et al., 2018; Ünal & Shao, 2019).

The CE can also be defined as a sustainable development initiative aimed at reducing the linear flows of materials and energy within society's production–consumption systems by applying material cycles and renewable energy flows. The circular economy promotes high-value material cycles along with more traditional recycling and develops systemic approaches for cooperation among producers, consumers, and other social actors in the pursuit of sustainable development (Korhonen et al., 2018; Ünal & Shao, 2019).

Ellen MacArthur Foundation (2019, p. 19) defines the Circular Economy (CE) as follows:

> "The circular economy is a systemic approach to economic development designed to benefit businesses, society, and the environment. A circular economy aims to decouple economic growth from the consumption of finite resources and to create economic, natural, and social capital. Supported by a transition to renewable energy sources and an increased use of renewable materials, the concept recognizes the importance of an economy that functions efficiently at all scales. This highlights the need for collaboration and active participation between small and large businesses, as well as among countries, cities, local communities, and individuals. This type of distributed, diverse, and inclusive economy will be better positioned to create and share the benefits of a circular economy. The model distinguishes between biological and technical cycles (see Figure 4). In biological cycles, food and bio-based materials (such as cotton or wood) return to the system through processes such as composting and anaerobic digestion. These cycles regenerate living systems (such as soil), which provide renewable resources

for the economy. Technical cycles recover and restore products, components, and materials through strategies such as reuse, repair, remanufacturing, or, as a last resort, recycling. Digital technology has the power to support the transition to a circular economy by significantly increasing virtualization, dematerialization, transparency, and feedback-driven intelligence" (Ellen MacArthur Foundation, 2019, p. 19).

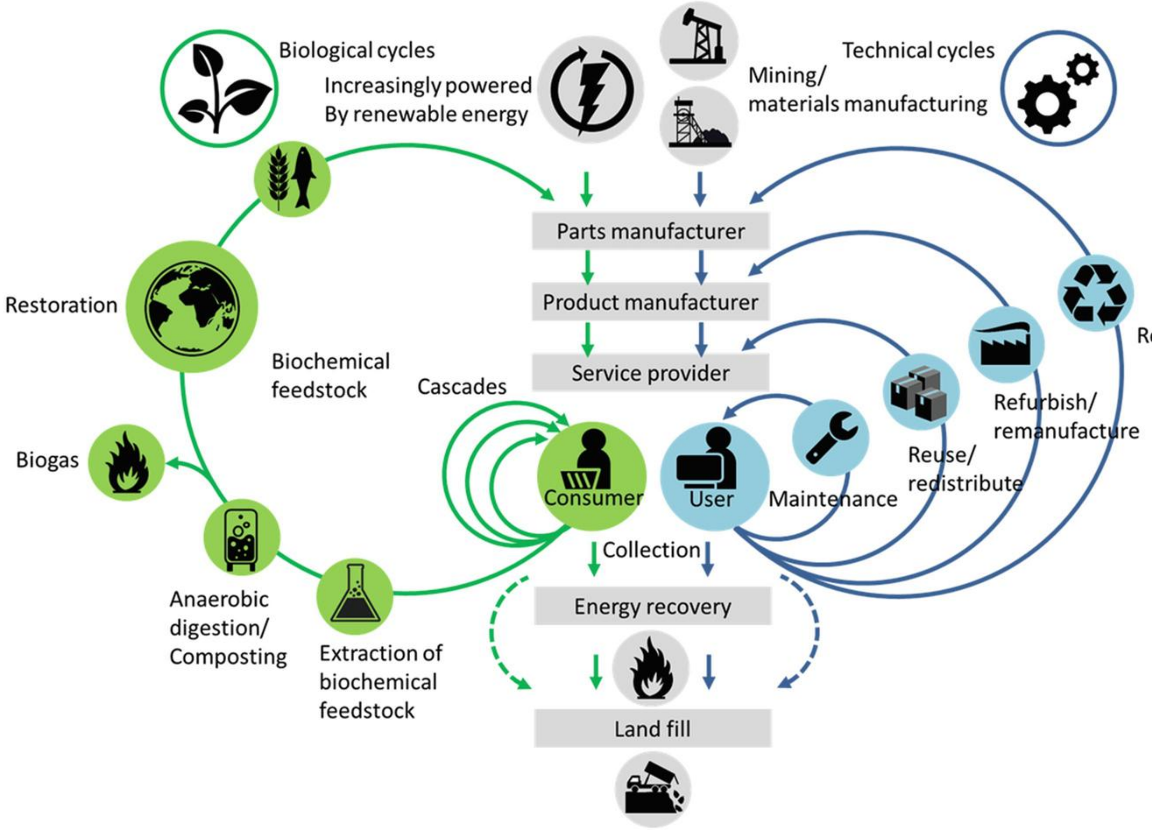

Figure 4: Circular Economy System Diagram
Source: Ellen MacArthur Foundation (2019, p. 20)

According to the concept of the Circular Economy (CE) presented by the Ellen MacArthur Foundation (2019), Figure 4 illustrates, in diagram form, how a circular economy system operates, considering both the biological cycle and the technical cycle. It can be observed that, in order to achieve the objective of maintaining products, components, and materials at their highest level of utility and value at all times, some strategies are employed, such as reuse, repair, remanufacturing, or recycling.

Salvador et al. (2020) state that the CE suggests that human activities should follow the example of nature. In nature, everything becomes an input for another process, forming a circular behavior. Therefore, human activities should behave in a similar way, resembling how nature performs its natural processes. Ertz et al. (2019) argue that the CE was proposed to limit the threats associated with excessive waste. The CE promotes resource-oriented strategies and suggests that, while some researchers claim that the CE can foster economic growth, increased circularity may promote the production of goods in subsequent cycles (Salvador et al., 2020).

Gallego-Schmid et al. (2020) emphasize that the CE model can be defined as a regenerative system in which resource waste, emissions, and energy leakage are minimized by slowing, closing, and narrowing material and energy cycles. Slowing resource cycles implies extending and intensifying the use of products to retain their value over time, while closing resource cycles facilitates reuse to restore or create new value from used materials. Finally, narrowing resource cycles involves eco-efficient solutions that reduce resource intensity and environmental impacts per unit of product or service.

The CE also denotes a manufacturing process or system that is restorative in nature. In a circular economy, the system is designed to replace the notion of end-of-life, emphasizing alternative and renewable energy sources while reducing the use of hazardous chemicals in manufacturing processes. The CE transforms production and consumption processes by creating value from discarded waste. It goes beyond current business models based on production and consumption and aims to develop a closed-loop system. The concept of the CE is based on three main principles: designing out waste, keeping products in use, and regenerating natural systems. Organizations need to adopt CE principles to increase circularity and further extend the longevity of resources. Factors such as current technological use, supply chain complexity, operations strategy, planning and control, regulations, and public awareness must be considered when implementing and promoting the CE (Bag et al., 2021).

Dantas et al. (2021) state that the Circular Economy (CE) is a concept that describes a paradigm shift regarding the use and disposal of materials and resources. It fundamentally opposes the production and consumption behaviors and patterns in which our society is currently embedded. The CE proposes an innovative pathway for sustainable development by introducing a different way of perceiving value in the management of natural resources. The CE can be understood as a systemic shift toward an economically viable yet regenerative model, grounded in the reintegration of used resources through material cycles (technological and biological). The CE promotes the minimization of resource consumption, waste generation, and emissions, while simultaneously ensuring socioeconomic development. Thus, the CE is developed around the idea of a systemic transformation directly related to resource extraction, waste generation, product design, environmental awareness, innovative business models, and integrative policies.

In a circular economy, the use of non-renewable resources and the generation of waste are minimized, while reuse and recycling dominate the life cycles of materials (Rosenboom, Langer, & Traverso, 2022).

Yu, Khan, and Umar (2022) state that the concept of the CE—through practices such as remanufacturing, reuse, and recycling—has addressed the problem of natural resource scarcity created by the linear approach (i.e., produce, consume, and discard). In supply chains, the CE includes different practices such as circular procurement, which is linked to cooperation with suppliers and the purchase of materials that can be easily remanufactured and recycled (Khan & Yu, 2021; Muranko et al., 2019), and circular design, which facilitates reverse logistics and green manufacturing. This approach is related to designing and manufacturing products or materials in a way that generates fewer emissions and harmful waste (Dumée, 2022; Khan et al., 2021).

Khan et al. (2022) emphasize that the CE refers to a cyclical approach to the production process, namely producing, using, recovering, recycling, and remanufacturing. Typically, the 3Rs (reduce, reuse, and recycle) are considered the core of a circular economy. A circular economy requires a broader and more comprehensive supply chain involving industry, societies, and individuals. It manages environmental challenges across different layers, including green environments, industrial zones, individual startups, and larger regions.

After analyzing the concept of the CE presented by several authors, it can be observed that certain terms frequently appear across different definitions. In this regard, ten terms that stand out the most were identified: cyclical, resource efficiency, highest utility and value, environment, recycling, regenerative, remanufacturing, restorative, reuse, and sustainability. Some authors did not necessarily use these exact terms but conveyed concepts that correspond to them. Therefore, a table was developed presenting the authors and the terms each author used to formulate their concept of the circular economy. A summary of these concepts can be seen in Table 1, which synthesizes the definitions presented in this section.

Authors	Cyclical	Resource Efficiency	Highest Utility and Value	Environment	Recycling	Regenerative	Remanufacturing	Restorative	Reuse	Sustainability
Bag *et al.* (2021)	X		X	X	X	X		X		X
Blomsma e Brennan, (2017)		X			X		X		X	
BSI (2017)			X	X		X		X	X	X
Dantas *et al.* (2021)	X	X		X	X	X				X
Ellen MacArthur Foundation (2013) e Ellen MacArthur Foundation (2019)	X	X	X	X	X	X	X	X	X	X
Esposito, Tse e Soufani (2018)	X	X	X			X		X		
Gallego-Schmid *et al.* (2020)	X	X	X	X		X		X	X	X
Haas *et al.* (2015)	X	X								X
Haupt, Vadenbo e Hellweg (2017)		X			X				X	
Heyes *et al.* (2018)		X		X						X
Hobson (2016)	X	X	X	X		X		X		X
Hopkinson *et al.* (2018)	X	X	X			X		X		
Jabbour *et al.* (2019)	X	X	X			X		X		
Khan *et al.* (2022)	X			X	X		X		X	X
Korhonen *et al.* (2018)	X	X		X	X					X
Ma *et al.* (2014)				X						X
Ma *et al.* (2015)	X	X		X						X
Moreau *et al.* (2017)	X	X	X			X		X		
Naustdalslid (2014)	X	X			X				X	
Niero *et al.* (2017)						X		X		
Rajput e Singh (2019)	X	X	X	X		X		X		X
Rosenboom, Langer e Traverso (2022)	X	X			X				X	
Salvador *et al.* (2020)	X	X		X						X
Sandoval, Jaca e Ormazabal (2018)	X	X	X		X				X	X
Singh e Ordonez (2016)	X	X								X
Stahel (2016)	X	X	X		X				X	X
Ünal e Shao (2019)	X	X		X	X					X
Wu et al. (2014)		X		X	X					X
Yu, Khan e Umar (2022)	X	X			X		X		X	

Table 1: Terms Used in the Definition of the Circular Economy
Source: Prepared by the author

Based on all the concepts presented, the Circular Economy (CE) in this study can be defined as a cyclical economic system that focuses on maximizing the lifespan of products, materials, and components in order to increase their utility and value. The circular economy is regenerative and restorative by design, promoting practices such as remanufacturing, recycling, and reuse to minimize waste and environmental impact, thereby creating a more sustainable and resilient economy.

After defining the concept of the CE, the next section presents the principles that guide it.

2.1.2 Principles of the Circular Economy

Genovese et al. (2015) emphasize that, from an idealistic perspective, the principles of the Circular Economy (CE) assume that the raw materials used in production systems should be technical and biological. These raw materials should not have a negative impact on the environment and should be regenerative, returning to the ecosystem without the need for treatments to rebuild natural capital. In essence, there would be no degradation or environmental impact from materials within a production system operating in a restorative cycle. However, since the concept of the circular economy is subject to the universal laws of thermodynamics, there would still be some degradation of raw materials in a production system over time. This occurs because circular flows of exchanges are coupled with physical flows of matter and energy, which are not circular. Thus, resource flows are ultimately linear and unidirectional, beginning with the depletion of low-entropy resources from the environment and ending with environmental pollution through high-entropy waste. Nevertheless, the CE aims to ensure that materials are used for as long as possible.

Wu et al. (2014) emphasize that the CE is based on the core principles of the 3Rs (reduce, reuse, and recycle) to achieve its objectives, which include reducing the use of natural resources, reducing pollution emissions, minimizing waste, reusing production residues, and recycling technically unusable waste.

Ellen MacArthur Foundation (2015, p. 7) presents the following basic principles of the Circular Economy:

> "1 – Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows;
> 2 – Optimize resource yields by circulating products, components, and materials at their highest level of utility at all times, in both the technical and biological cycles;
> 3 – Foster system effectiveness by identifying and eliminating negative externalities from the outset (Ellen MacArthur Foundation, 2015, p. 7).

According to Ghisellini, Cialani, and Ulgiati (2016), the 3R principle (Reduce, Reuse, and Recycle) can be understood as follows:

- The principle of reduction aims to minimize the input of primary energy, raw materials, and waste through improvements in production efficiency (so-called eco-efficiency) and consumption processes. Examples include introducing better technologies, more compact and lightweight products, simplified packaging, more efficient household appliances, and simpler lifestyles. Eco-efficiency is primarily a business-oriented concept focusing on the economic and environmental dimensions of sustainability. The concept of resource efficiency implies reducing resource use while simultaneously increasing economic and social well-being. From the production perspective, there are two basic ways in which companies can increase eco-efficiency in their production processes: maintaining or increasing the value of products while reducing their environmental impacts. This can be achieved by using fewer resources per unit of value produced and by substituting more harmful substances with less harmful ones per unit of value produced.
- The principle of reuse refers to any operation by which products or components that are not waste are reused for the same purpose for which they were originally designed. Product reuse has many environmental benefits because it requires fewer resources, less energy, and less labor compared with manufacturing new products from virgin materials. The diffusion of reuse involves increasing consumer demand for reused and remanufactured products, designing durable products for multiple use cycles, and creating incentives for companies to encourage product returns and the commercialization of remanufactured products.
- The principle of recycling refers to any recovery operation in which waste is reprocessed into products, materials, or substances, whether for the original purpose or other purposes. Waste recycling offers the opportunity to benefit from still-usable resources and reduce the amount of waste that needs to be treated or disposed of, thereby also reducing the associated environmental impact. However, if a company or society can recycle all of its waste, it may not be motivated to reduce the amount of waste generated.

These same authors, in addition to the 3R principles, mention three additional principles that can support the Circular Economy:

- Appropriate design: emphasizes the importance of the design stage in seeking solutions to avoid waste disposal in landfills. Products are designed for disassembly and reuse cycles;
- Reclassification: introduces a reclassification of materials into technical materials and nutrients. Technical materials (such as metals and plastics) are designed to be reused at the end of their life cycle, while nutrients or biological nutrients, which are generally non-toxic, can safely return to the biosphere or enter cascades of consecutive uses;
- Renewability: places renewable energy as the primary energy source for the circular economy in order to reduce dependence on fossil energy and increase the adaptability (resilience) of the economic system to the negative effects of oil dependence.

Ghisellini, Cialani, and Ulgiati (2016) proposed a table summarizing the main limitations and challenges of developing the Circular Economy, as presented in Table 2.

Jawahir and Bradley (2016) define the 6R methodology by considering the 3R principles proposed by Ghisellini, Cialani, and Ulgiati (2016) and adding additional Rs as follows: recovery, which consists of the process of collecting products at the end of the use phase, disassembling, sorting, and cleaning them for use in subsequent product life cycles; redesign, which involves redesigning next-generation products that use components, materials, and resources recovered from previous product life cycles; and remanufacturing, which involves reprocessing used products to restore them to their original condition or to a like-new state by reusing as many parts as possible without loss of functionality.

Jawahir and Bradley (2016) and Han et al. (2017) emphasize that the main objective of the Circular Economy (CE) is to achieve sustainable development by following the principles of the 3Rs (reduce, reuse, and recycle) and the 6Rs (reuse, recycle, redesign, remanufacture, reduce, and recover).

Circular Economy Principles	Limits or Challenges
Design	Ideal product lifetime scenario.
	Design for disassembly, reuse, and recycling.
	Design for durable products.
	Design for new consumption business models.
Reduction	Overcoming the rebound effect of eco-efficiency and eco-sufficiency strategies.
Reuse	Maximum technical reuse of materials.
	Increased consumer demand for the reuse of products and materials.
	Development of company return mechanisms.
	Ensuring repair and secondary use of products after their original use.
	Taxation based on non-renewable energy instead of labor and renewable energy.
Recycle	Strengthening local markets for recycled materials.
	Risks associated with the global trade of materials. Plastic waste: infeasibility due to contaminant mixtures.
	Cellulose: viable up to 4 to 6 cycles.
	Rare metals: lack of economies of scale.
	Food waste: other transformations before use require high research and development costs.
	Proper Life Cycle Assessment modeling for reuse and recycling.
Reclassification of materials into: Technical and Nutrients	Reuse after the first cycle.
	Safe return to the biosphere or cascading uses (biorefinery).
Renewable Energy	Increase its share relative to fossil fuels.

Table 2: Main Limits and Challenges of the Transition to the Circular Economy
Source: Adapted from Ghisellini, Cialani e Ulgiati (2016)

Elia, Gnoni, and Tornese (2017) present four categories of actions for implementing the CE:

- Design and production of circular products: several actions can be included in this category, starting with ecodesign methods aimed at facilitating the reuse, refurbishment, and recycling of products, as well as the design of products and processes using less hazardous substances;
- Business models: this category mainly includes the diffusion of new models such as product–service systems instead of product ownership, as well as collaborative consumption tools based on a broader diffusion of consumer-to-consumer channels;
- Cascading/reverse competencies: interventions mainly focus on supporting closed loops, for example through innovative technologies for high-quality recycling that help avoid downcycling, or through cascading uses of materials where high-quality recycling is not feasible. More efficient support for secondary raw material markets will also be essential;

- Collaboration between cycles and sectors: actions in this category focus on building a new value chain that is collaborative across its entire length and involves new actors, preventing by-products from becoming waste through industrial symbiosis.

The Ellen MacArthur Foundation (2019) addresses the three principles of the CE and presents considerations on how these principles can be achieved. The three principles are: eliminate waste and pollution; keep products and materials in use; and regenerate natural systems.

According to the Ellen MacArthur Foundation (2019), to eliminate waste and pollution three fundamental strategies are proposed: design for circularity, waste elimination, and material substitution. Design for circularity emphasizes the importance of designing products to facilitate disassembly, repair, recycling, and reuse. Waste elimination is achieved through material efficiency and emerging technologies. Material substitution focuses on the use of renewable or recycled (recyclable) materials. The second principle, keep products and materials in use, highlights strategies such as material recirculation and product reuse. Recycling is emphasized by reducing greenhouse gas (GHG) emissions and extending product lifetimes. Reuse aims to preserve the embodied energy and resources used in manufacturing. The third principle, regenerate natural systems, highlights the importance of using renewable resources and improving natural systems, with emphasis on regenerative agriculture to promote systemic benefits and carbon sequestration.

Awan, Sroufe, and Shahbaz (2021) highlight two CE principles: recycling and reuse. Recycling is limited to the resource cycle and focuses on increasing the lifespan of materials, parts, and reused products through improved maintenance of operations and manufacturing processes. The concept of recycling refers to any recovery operation through which waste is reprocessed into products or materials, either for the original purpose or for other purposes. Reuse refers to the use of a product for its maximum useful life. The principle of reuse refers to any operation in which products or components that are not waste are used again for the same purpose for which they were originally designed.

Table 3 presents a comparison of the Rs cited by each author as principles of the Circular Economy.

Authors	Recycle	Recover	Redesign	Reduce	Remanufacture	Reuse
Awan, Sroufe e Shahbaz (2021)	X					X
Elia, Gnoni e Tornese (2017)	X	X				X
Ellen MacArthur Foundation (2019)	X	X				X
Ghisellini, Cialani e Ulgiati (2016)	X			X		X
Han *et al.* (2017)	X	X	X	X	X	X
Jawahir e Bradley (2016)	X	X	X	X	X	X
Wu *et al.* (2014)	X			X		X

Table 3: Rs Cited by Each Author as Principles of the Circular Economy
Source: Prepared by the author

After understanding the principles of the Circular Economy (CE), it is important to know how this economy can be measured. Therefore, some indicators are presented in the next section.

2.1.3 Indicators for the Circular Economy

In order to determine whether organizations are on the right path toward the implementation and practice of the Circular Economy (CE), several authors propose strategies to measure circularity.

Circularity metrics are useful for evaluating the effects of a circular economy in terms of profitability and environmental impacts (Linder, Sarasini, & Van Loon, 2017).

Linder, Sarasini, and Van Loon (2017) suggest using economic value as the basic unit to aggregate product parts in a circularity metric at the product level, where circularity is defined as the fraction of a product that originates from used products. Based on this reasoning, a metric can be outlined using the relationship between recirculated value and the total economic value of the product.

According to Pauliuk (2018), quantitative indicators are essential for assessing the performance of an organization or product system in relation to CE principles and sustainability objectives. In this context, the author presents a list of indicators to measure circularity, monetary value, and potential impacts, based on Material Flow Analysis (MFA), Material Flow Cost Accounting (MFCA), and Life Cycle Assessment (LCA).

Figge et al. (2018) emphasize that in the CE material resources circulate and remain within production systems. Therefore, the circularity of such resources requires a metric that examines supply chains to determine the inputs and outputs of specific resources (and their combinations), from their primary extraction to their eventual disposal as waste. In theory, monitoring resource flows allows companies to adopt practices that maximize the use of materials derived from recovery and recycling while minimizing the use of virgin resources.

An alternative way to measure the eco-efficiency of virgin resources is to emphasize longevity, that is, the period during which a resource is used, which can be measured in days, months, years, and so on. The idea is that the longer a resource is used, the greater its contribution to a circular economy. High circularity is still important, but only to the extent that it contributes to extending the time during which a resource remains active (Franklin-Johnson, Figge, & Canning, 2016; Figge et al., 2018).

According to Franklin-Johnson, Figge, and Canning (2016) and Figge et al. (2018), longevity is determined in three ways: the time during which a resource is used for the first time (A); the time during which a resource is used due to product refurbishment (B); and the time resulting from recycling (C). The same authors illustrate longevity as follows: consider a process in which products undergo refurbishment and resources are recycled, both performed at most twice. Thus, longevity is defined as the aggregation of three contributions: the initial lifetime of the product, the contribution derived from the lifetime of the refurbished product, and the contribution from the recycled life.

Niero and Kalbar (2019) proposed a multicriteria decision analysis to measure circularity using two sets of indicators: (i) indicators based on material circularity (material reuse score and the Material Circularity Indicator), and (ii) a selection of life cycle–based indicators relevant to beer packaging, namely climate change, abiotic resource depletion, acidification, particulate matter, and water consumption.

A case study was conducted on beer packaging, simulating a situation in which a company aims to compare the performance of different packaging options from a CE perspective. Eight different beer packaging alternatives were considered in two geographical contexts (the United Kingdom and India). The results obtained through the application of the TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution) show that different sets of indicators can be integrated and that conflicts between them can be resolved (Niero & Kalbar, 2019).

Table 4 presents a comparison of the indicators cited by each author as measures used in the Circular Economy.

Authors	Circularity	Material Flow	Longevity	Potential Impacts	Monetary Value
Figge *et al.* (2018)	X	X	X		
Franklin-Johnson, Figge, Canning (2016)			X		
Linder, Sarasini e van Loon (2017)	X				
Niero e Kalbar (2019)	X	X			
Pauliuk (2018)	X	X		X	X

Table 4: Indicators Cited by Each Author Used in the Circular Economy
Source: Prepared by the author

After analyzing the definition, principles, and indicators of the Circular Economy (CE), it is necessary to understand two important concepts that are directly related to the CE: reverse logistics and the product life cycle. First, the next section analyzes reverse logistics.

2.1.4 Reverse Logistics

Reverse logistics refers to the process of moving products or materials from the consumer back to the point of origin, whether for recycling, reuse, remanufacturing, or proper disposal. Unlike conventional logistics, which involves the movement of products from the manufacturer to the consumer, reverse logistics encompasses the reverse flow (Genovese et al., 2015; Wang, Burke, & Zhang, 2022).

According to Almeida, Borsato, and Ugaya (2017); Bocken et al. (2016); Dokter, Thuvander, and Rahe (2021); Franco (2017); Huertas et al. (2013); Joustra et al. (2022); Jugend et al. (2020); Khan and Haleem (2021); Loon, Diener, and Harris (2021); Sumter et al. (2021); Urbinati, Chiaroni, and Toletti (2019); and Wang, Burke, and Zhang (2022), reverse logistics may present several operational barriers to the effective implementation of the Circular Economy (CE) in supply chains. Reverse logistics can act as a barrier to the circular economy for several reasons:

- Inadequate infrastructure: many supply chains were originally designed for a linear flow of products from manufacturers to consumers, making them unsuitable for efficiently handling the return of products and materials. The lack of specialized infrastructure for reverse logistics can hinder the effective implementation of the circular economy.
- Operational complexity: reverse logistics involves the collection, transportation, disassembly, recycling, or remanufacturing of used products. These additional operations introduce complexity into supply chain

operational decisions, including scheduling, capacity planning, and inventory control, making the process more challenging and costly.

- Lack of collaboration in the supply chain: the efficiency of reverse logistics often depends on collaboration among several supply chain participants, including manufacturers, retailers, carriers, and recycling organizations. A lack of cooperation may result in gaps in the effective implementation of reverse logistics and, consequently, the circular economy.
- Resistance to change: shifting from a linear to a circular model requires redefining business practices and adopting a more proactive approach to product lifecycle management. Many companies may resist these changes, especially if they involve additional costs or disruptions to existing operations.
- Technological challenges: the effective implementation of reverse logistics in the circular economy often requires advanced technologies, such as tracking systems, sensors, and blockchain, to monitor and trace products throughout the supply chain. The adoption of such technologies may be a barrier for some organizations.

Some barriers include the lack of adequate infrastructure for reverse logistics and disassembly, the misalignment of existing linear supply chain design, and the increasing complexity of operational decisions. Current supply chain infrastructure is not prepared to support comprehensive reverse logistics and disassembly activities required for material circularity. Collaboration among supply chain partners is highlighted as crucial for overcoming these barriers. Inadequate infrastructure is identified as a significant barrier affecting efficiency in the collection of returned products and reverse logistics processes. Additionally, the lack of cross-sector collaborations, infrastructure for waste trading, and the need for strategic investments in reverse logistics are emphasized as critical areas to address in order to advance the circular economy (Wang, Burke, & Zhang, 2022).

In the study conducted by Dokter, Thuvander, and Rahe (2021), interviewed architects emphasized reverse logistics as a significant challenge for the recirculation of materials in the built environment, citing practical, environmental, and economic concerns. With the increasing reuse and recycling of construction waste, difficulties arise regarding the storage and transportation of these materials. It is suggested that waste treatment companies could play a systemic role by acting as material suppliers in building design, thereby increasing the feasibility of reuse strategies and reducing logistical risks. One example involved carpenters acting as logistics partners in an interior design project, assuming responsibility for acquiring and storing reused furniture and components, highlighting a more integrated approach to material management in the construction process.

According to Atlason, Giacalone, and Parajuly (2017); Franco (2017); Jugend et al. (2020); Khan and Haleem (2021); Moreno et al. (2016); Oliveira et al. (2016); Sumter et al. (2020); Vihma and Moora (2020); and Wang, Burke, and Zhang (2022), reverse logistics plays a fundamental role in implementing the circular economy by facilitating the return of products, materials, and components to the value chain, promoting more sustainable practices. Some ways in which reverse logistics can contribute to the circular economy include:

- Reuse and remanufacturing: reverse logistics enables the collection of used products to be reused or remanufactured. These products can be repaired, upgraded, and reintroduced into the market, extending their life cycle and reducing the need for new raw materials.
- Efficient recycling: reverse logistics facilitates the collection of waste and discarded materials, directing them to recycling facilities. This promotes the recovery of valuable materials and the production of secondary raw materials, reducing dependence on virgin resources.
- Waste reduction: by integrating reverse logistics into the supply chain, there is a significant reduction in the amount of waste sent to landfills. This contributes to environmental sustainability goals by preventing waste accumulation and minimizing negative environmental impacts.
- Environmental awareness: reverse logistics promotes a cultural shift toward environmental awareness by encouraging consumers, manufacturers, and retailers to consider the full life cycle of products. This can lead to more sustainable decisions regarding product design, packaging, and consumption practices.
- Resource efficiency: by reintegrating materials and products into the value chain, reverse logistics contributes to resource efficiency, avoiding

excessive extraction of raw materials and reducing the demand for new products. This aligns with the fundamental principles of the circular economy, which seeks to minimize waste and maximize the value of existing resources.

- More sustainable supply chains: the effective implementation of reverse logistics requires a collaborative approach among supply chain participants. This creates a more sustainability-oriented mindset and may lead to positive changes throughout the supply chain, from product design to responsible disposal.

Boorsma et al. (2022) present an example of reverse logistics application related to the circular economy. According to these authors, imaging devices used in professional contexts often incorporate several high-value components, making reverse logistics and remanufacturing economically viable. For example, many printers contain printheads that represent the majority of the equipment's value. In the case of this specific product, the combination of collecting components—such as removing the printheads—and complete remanufacturing enables the effective implementation of the process.

Khan and Haleem (2021) highlight the creation of an ecosystem centered on reverse logistics for electronic devices. The collection of old phones occurs in the company's retail stores and they are subsequently sent to a nonprofit organization responsible for evaluating the condition of the devices and determining the most appropriate strategy. If a device is not suitable for reuse, the organization directs it to recycling facilities.

After presenting and analyzing the concept of reverse logistics, it is important to examine another concept related to the Circular Economy: the product life cycle, which is addressed in the next section.

2.1.5 Life Cycle

According to Asif et al. (2021), Boorsma et al. (2022), Bressanelli et al. (2020), Diaz et al. (2021), Diaz, Reyes, and Baumgartner (2022), Fernando et al. (2021), Gagnon et al. (2022), He et al. (2021), Joustra et al. (2022), Joustra, Flipsen, and Balkenende (2021), Jugend et al. (2020), Leal et al. (2020), Pérez-Ortega et al. (2021), and Vimal et al. (2022), the product life cycle plays a crucial role in the transition to a circular economy, where the objective is to optimize the use of resources, minimize waste, and promote sustainability. Some ways in which the life cycle influences the circular economy include:

- Sustainable design: during the product design phase, considerations that facilitate disassembly, repair, and recycling are essential. Intelligent design can extend product lifespan and facilitate the reintegration of materials into the production cycle.
- Extension of product lifespan: strategies to prolong the lifespan of products, such as maintenance, repair, and upgrades, are essential for the circular economy. This reduces the need to produce new items frequently.
- Refurbishment and reuse: during the maturity and decline phases, the circular economy encourages the refurbishment and reuse of products. This may occur through second-hand markets, buy-back programs, and other initiatives that keep products in circulation.
- Efficient recycling: at the end of the product life cycle, the circular economy emphasizes the importance of efficient recycling systems. This involves selective material collection, effective recycling processes, and reintegration of these materials into production.
- Reverse logistics: the implementation of reverse logistics systems is crucial for the circular economy. This involves the collection and return of discarded products for recycling, refurbishment, or proper disposal.
- Conscious consumption: awareness of the product life cycle encourages more responsible consumption, motivating consumers to make informed choices considering durability, ease of repair, and environmental impacts.
- Innovation and technology: the circular economy encourages innovation in new technologies and processes that facilitate recycling, reuse, and efficient resource management throughout the product life cycle.

According to Desing, Braun, and Hischier (2021), Ford and Fisher (2019), Lama et al. (2022), Pamminger, Glaser, and Wimmer (2021), Pérez-Ortega et al. (2021), Shahbazi and Jönbrink (2020), Spreafico (2022), and Vimal et al. (2022), Life Cycle Assessment (LCA) is an essential tool that can play a significant role in implementing the circular economy. LCA is a systematic approach used to evaluate the environmental impacts of a product or service throughout its entire life cycle, from raw material extraction to final disposal. Some ways in which LCA can support the transition to a circular economy include:

- Identifying improvement opportunities: LCA helps identify critical points and significant environmental impacts throughout a product's life cycle. This allows companies to identify specific areas where more circular practices can be implemented, such as sustainable design, material reuse, or optimization of production processes.
- Designing for circularity: LCA can guide product design by considering circular aspects from the beginning. Environmental impact assessments can inform design decisions that promote durability, ease of disassembly, repair, and recycling.
- Evidence-based decision making: LCA provides tangible data and evidence about environmental impacts associated with different options throughout the life cycle. This enables companies to make informed decisions regarding more sustainable and economically viable practices.
- Evaluating alternatives and materials: LCA can be used to compare different material alternatives and production processes. This is crucial in the circular economy, where material selection must consider recyclability, reuse, and other circular criteria.
- Establishing goals and performance indicators: based on LCA results, companies can establish specific goals and performance indicators to improve product sustainability. These may include targets related to resource efficiency, waste reduction, and maximizing product lifespan.
- Supporting sustainable communication and marketing: LCA provides a solid basis for transparent and sustainable communication. Companies can highlight their circular initiatives and demonstrate commitment to responsible resource management and environmental impact reduction.
- Assessing impacts across supply chains: LCA can be extended to evaluate impacts throughout the entire supply chain, helping companies better understand how their decisions affect sustainability at different stages of production and distribution.

After analyzing the concepts related to the Circular Economy, it is important to examine the legislation associated with the CE, which is presented in the next section.

2.1.6 Legislation

The 2030 Agenda for Sustainable Development is a global action plan aimed at eradicating poverty, protecting the planet, and promoting prosperity and universal peace. Recognizing poverty eradication as the greatest global challenge, the agenda seeks to transform the world through 17 Sustainable Development Goals (SDGs) and 169 targets, integrating the economic, social, and environmental dimensions of development. With the collaboration of all countries and stakeholders, the plan aims to ensure that no one is left behind and promotes human rights, gender equality, and the empowerment of women and girls (United Nations, 2015).

According to the United Nations (2015), the SDGs are:

1. No Poverty: end poverty in all its forms everywhere.
2. Zero Hunger and Sustainable Agriculture: end hunger, achieve food security and improved nutrition, and promote sustainable agriculture.
3. Good Health and Well-Being: ensure healthy lives and promote well-being for all at all ages.
4. Quality Education: ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
5. Gender Equality: achieve gender equality and empower all women and girls.
6. Clean Water and Sanitation: ensure availability and sustainable management of water and sanitation for all.
7. Affordable and Clean Energy: ensure access to affordable, reliable, sustainable, and modern energy for all.
8. Decent Work and Economic Growth: promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.
9. Industry, Innovation and Infrastructure: build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.
10. Reduced Inequalities: reduce inequality within and among countries.

11. Sustainable Cities and Communities: make cities and human settlements inclusive, safe, resilient, and sustainable.
12. Responsible Consumption and Production: ensure sustainable consumption and production patterns.
13. Climate Action: take urgent action to combat climate change and its impacts.
14. Life Below Water: conserve and sustainably use the oceans, seas, and marine resources for sustainable development.
15. Life on Land: protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss.
16. Peace, Justice and Strong Institutions: promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels.
17. Partnerships for the Goals: strengthen the means of implementation and revitalize the global partnership for sustainable development.

In Brazil, it can be considered that the SDGs and Circular Economy (CE) concepts began to be reflected in legislation with the National Solid Waste Policy (PNRS) enacted in 2010. Ojima (2023) states that the principles and objectives of the PNRS are associated with CE concepts and are aligned with several SDGs established by the United Nations in the 2030 Agenda.

According to Article 4 of Law No. 12,305 of August 2, 2010, the PNRS encompasses the principles, objectives, instruments, guidelines, targets, and actions implemented by the Federal Government, either independently or in cooperation with states, the Federal District, municipalities, or private entities, aiming at the integrated management and environmentally sound management of solid waste (Brazil, 2010).

Article 3 of the PNRS law includes several concepts related to the Circular Economy, such as product life cycle, selective collection, environmentally appropriate final destination, environmentally appropriate final disposal, solid waste management, reverse logistics, sustainable production and consumption patterns, recycling, and reuse (Brazil, 2010).

Currently, Bill No. 1874 of 2022 is under consideration in the Brazilian National Congress, which proposes the establishment of the National Circular Economy Policy (PNEC). Article 2 of the PNEC presents important concepts related to the CE, such as value addition, product life cycle, circularity, circular economy, low-carbon technologies, refurbishment, value recovery, reduction by design, remanufacturing, repair, reuse, just transition, and value (Brazil, 2022).

Article 3 of the PNEC presents the following objectives:

> I – promote strategic management, mapping, and tracking of resource stocks and flows within the national territory;
> II – promote new business models based on circularity criteria and related solutions;
> III – strengthen value chains through the addition, retention, and recovery of resource value;
> IV – encourage research, development, and innovation to promote circularity;
> V – raise societal awareness regarding the efficient use of resources, products, and materials;
> VI – stimulate the supply of circular economy solutions;
> VII – encourage activities related to the circular economy as a strategy for the country's economic and social development (Brazil, 2022).
> Article 1 of the PNEC presents the following principles:
> I – elimination of waste and pollution from the beginning of the production chain of goods and services;
> II – maintenance of the value of resources, products, and materials in use for as long as possible;
> III – regeneration of natural systems;
> IV – systemic thinking in resource management, considering the impacts of interactions among environmental, social, and economic systems, taking into account the life cycle perspective of solutions;
> V – regeneration, retention, or addition of value by providing effective solutions that use resources efficiently and contribute to meeting societal needs;
> VI – minimization of non-renewable resource extraction and management of renewable resources to regenerate and increase value over time;
> VII – value sharing, where organizations and stakeholders collaborate throughout the value chain or network in an inclusive and equitable manner for the benefit and well-being of society;
> VIII – traceability of resource stocks and flows in a transparent and responsible manner, ensuring the regeneration, retention, or addition of value while maintaining circular resource flows;

IX – ecosystem resilience promoted through organizational practices and strategies that contribute to the regeneration of natural resources and biodiversity;
X – encouragement of sustainable consumption;
XI – promotion of a just transition (Brazil, 2022).

On June 27, 2024, Decree No. 12,082 was published, establishing the National Circular Economy Strategy (ENEC). Article 2 of the ENEC provides a definition of the Circular Economy that aligns with the definitions presented in Section 2.1.1. Articles 3 and 4 establish guidelines and objectives related to CE principles, indicator concepts, and life cycle approaches discussed in Sections 2.1.2, 2.1.3, and 2.1.5 of this thesis.

The following characteristics of the ENEC decree can be highlighted (Brazil, 2024):

- maintaining the value of materials;
- reducing dependence on natural resources;
- promoting sustainable production and consumption;
- increasing the life cycle of all materials;
- establishing measurable targets, standards, and indicators to monitor circularity;
- developing markets for reusable, refurbished, and recycled products;
- encouraging reuse and extending product lifetimes;
- minimizing waste from the product design stage (Brazil, 2024).

Through the analysis of these legislative frameworks, it can be observed that Brazil is addressing environmental concerns through the implementation of Circular Economy strategies.

After presenting the concepts and legislation related to the Circular Economy, Section 2.1.7 presents the benefits that the CE can bring.

2.1.7 Benefits of the Circular Economy

Several authors present benefits associated with the application of the Circular Economy (CE) according to different contexts. In this sense, some examples of these benefits are presented below.

Amend et al. (2022) conducted an empirical analysis showing that users of SmartMod smartphones (a pioneer in sustainability) tend to adopt CE-oriented behaviors, since these smartphones are modular and designed to facilitate repair (either self-repair or repair by a professional service). The overall readiness for repair was comparatively high. Only 13% of modular smartphones and 15% of semi-modular smartphones were not repaired, while the percentage for conventional smartphones was 55%. This indicates that modularity facilitates successful repair behavior by making repairs easier.

Boorsma et al. (2022) report a case study in which remanufacturing was considered separate and secondary to the development and production of newly manufactured products. Due to this implicit status, there is a gap regarding an integrated design vision and business strategy for remanufacturing. Closing this gap can be achieved through design management to develop a design strategy aligned with product development for multiple use cycles. Failure to address this gap may produce suboptimal results and the risk of leaving remanufacturing as an isolated value-retention strategy. In its current form, the company in the case study utilizes only part of the potential value that design for remanufacturing can provide. The analyzed company chose business models that support favorable return rates in the market, such as offering products as a service. In this sense, the extent to which product design can support this is determined at the early stages of the project. Having an integrated design vision and business strategy that simultaneously considers manufacturing and remanufacturing would create opportunities to align with new product design, leverage the strategic value of remanufacturing, and increase company-wide adoption of remanufacturing.

The work conducted by Gagnon et al. (2022) focused on forest products that can be compatible with CE principles. Interviews were conducted with Canadian experts in ecodesign, circular economy, forest products, and/or waste management, with a focus on construction and packaging. Efforts made by forest industries in the production phase to reduce resource consumption were recognized, but the implementation of other CE strategies, such as reuse, recycling, and energy recovery, remains limited. Although opportunities exist for incremental improvements, such as processing recovered wood into wood panels and recycling cardboard fibers, these processes are viable only if cardboard is not mixed with other waste.

Joustra et al. (2022) emphasize that in order to evaluate the effectiveness of the circular composite sizing method, several cases were analyzed based on the level of integrity (product or material) and the nature of the recovery system (open or closed). All cases explored strategies related to material and product integrity. The value chain mapping revealed additional recovery pathways, leading to the exploration of several product integrity strategies. Most notably, extending product lifespan through repair was addressed in all cases. Thus, the design method, applied under the guidance of the method developers, provided designers with strategies beyond long-life cycles and recycling.

These interactions provided explicit product design requirements and an initial selection of strategies to be considered in design. The method, with its underlying life cycle mapping spreadsheet and design framework, is well structured and reflects the prioritization of recovery strategies in a circular economy. The design aspects build upon established industry practices and support designers in implementing CE strategies in product development (Joustra et al., 2022).

Ortner, Tay, and Wortmann (2022) used multi-objective optimization (MOO) to develop a product design based on CE principles. The design demonstrated contributions to cleaner production and reduced environmental impact. The case study presented a relatively large and robust optimization result, with a 23% reduction or a reduction of more than 4.7 kg CO_2 per unit of carbon emission. When multiplied by the many units produced for the case study or similar products, these optimizations would result in a significant reduction in environmental impact.

Vimal et al. (2022) proposed a model that promises positive impacts on social and environmental factors by encouraging communities to adopt more sustainable lifestyles. The proposed model involves a multifunctional team comprising design, planning, engineering, and quality control. This increases communication and commitment and therefore has positive managerial implications. The economic factor is also affected, since the initial investment in raw materials is directed toward material recovery. The company analyzed in the case study used Circular Function Deployment (CFD), which proved to be highly convenient. CFD consists of incorporating circularity concepts as requirements into Quality Function Deployment (QFD). It is also possible to conduct CFD considering only circularity requirements. Thus, the company can easily update its QFD practices to CFD. Through the new design, the organization was able to manufacture the product using less plastic, resulting in lower pollution and promoting a more sustainable lifestyle. The newly proposed toothbrush design reduced environmental impacts during manufacturing, use, disposal, and recovery phases. In the conventional toothbrush design, bristles are made of nylon. Nylon production generates nitrous oxide, a greenhouse gas, and the production of such harmful by-products is reduced in the new toothbrush design. The use of materials in complex consumer products is a crucial factor for improving circularity. By developing an innovative product design, the study proposes that the toothbrush be made entirely of recyclable material; therefore, the use of materials after recovery does not produce harmful by-products, unlike conventional toothbrush designs. CFD proved to be a highly efficient and fast tool for identifying significant parts that should be redesigned for circularity and improved sustainability.

Wang, Burke, and Zhang (2022) conducted a study proposing a roadmap for circular product design that encompasses critical points and supporting conditions at multiple levels (macro, meso, and micro). Overcoming barriers to circular product design requires collaborative efforts among all stakeholders involved. At the macro level, governments can enact legislation and use economic incentives to create a business environment that supports circular product design. Governments must work with communities to provide essential infrastructure for recovering value from end-of-life products and waste, such as waste collection and recycling facilities. They also need to partner with educational institutions in environmental education to foster a culture more receptive to circular products. At the meso level, establishing industrial symbiosis—often implemented in eco-industrial parks—facilitates the exchange of waste and resources among partner companies. At the micro level, companies must develop circular product design capabilities and reconfigure their supply chains (for example, reverse logistics and location strategies) to enable circular flows of products and materials. Government-supported initiatives may also help educate consumers about the environmental benefits of circular products.

Zikopoulos (2022) highlights that the environmental performance of remanufacturing systems is better than that of traditional manufacturing systems, as remanufacturing allows greater use of returned materials, lower material consumption per product user, and a greater number of units remaining in operation over two periods. In contrast, traditional manufacturing has disadvantages compared to remanufacturing in terms of virgin raw material consumption. However, regarding waste generation, both systems present equivalent outcomes.

Based on these studies, a table was developed containing 17 benefits classified into five categories of benefits that the Circular Economy can provide when related to product development. These categories are: Government, Organization, Repair, Recycling, and Remanufacturing. Table 5 presents several authors who identified these benefits in their studies, grouped according to the corresponding benefit and category.

Stakeholders	Benefits	Authors
Government	Provide essential infrastructure for the recovery of value from products and waste, such as waste collection and recycling facilities	Jugend *et al*. (2020); Khan e Haleem (2021); Sihvonen e Partanen (2016); Wang, Burke, e Zhang (2022)
	Enact legislation as an incentive	Fernando *et al*. (2021); Jugend *et al*. (2020); Khan e Haleem (2021); Ko (2020); Ofterdinger, Dlugoborskyte, e Herstatt (2021); Sihvonen e Partanen (2016); Wang, Burke, e Zhang (2022)
Organization	Circularity	Almeida, Borsato, e Ugaya (2017); Ameli, Mansour, e Ahmadi-Javid (2019); Asif *et al*. (2021); Batwara *et al*. (2022); Bovea e Pérez-Belis (2018); Bressanelli *et al*. (2020); Desing, Braun, e Hischier (2021); Diaz *et al*. (2021); Dokter, Thuvander, e Rahe (2021); Evrard *et al*. (2021); Fernando *et al*. (2021); Franco (2017); Gagnon *et al*. (2022); Hapuwatte e Jawahir (2021); He *et al*. (2021); Hollander, Bakker, e Hultink (2017); Huertas *et al*. (2013); Jiang *et al*. (2021); Khan e Haleem (2021); Loon, Diener, e Harris (2021); Mesa, Esparragoza, e Maury (2018); Mestre e Cooper (2017); Nag, Sharma, e Kumar (2022); Oliveira *et al*. (2016); Pamminger, Glaser, e Wimmer (2021); Pastor *et al*. (2022); Pérez-Ortega *et al*. (2021); Sihvonen e Partanen (2016); Sousa-Zomer *et al*. (2018); Sumter *et al*. (2020); Sumter *et al*. (2021); Urbinati, Chiaroni, e Toletti (2019); Vanegas *et al*. (2018); Vimal *et al*. (2022); Vinodh e Rathod (2010); Wang, Burke, e Zhang (2022)
	Sustainability factor	Ameli, Mansour, e Ahmadi-Javid (2019); Batwara *et al*. (2022); Bovea e Pérez-Belis (2012); Bovea e Pérez-Belis (2018); Chouinard *et al*. (2019); Eddy *et al*. (2014); Ford e Fisher (2019); Hapuwatte e Jawahir (2021); Hollander, Bakker, e Hultink (2017); Huertas *et al*. (2013); Khan e Haleem (2021); Ko (2020); Lama *et al*. (2022); Mesa, Esparragoza, e Maury (2018); Mestre e Cooper (2017); Mohagheghian *et al*. (2021); Nag, Sharma, e Kumar (2022); Pamminger, Glaser, e Wimmer (2021); Sihvonen e Partanen (2016); Spreafico (2022); Sumter *et al*. (2020); Sumter *et al*. (2021); Vimal *et al*. (2022); Vinodh e Rathod (2010); Vinodh *et al*. (2017)
	Reverse logistics	Atlason, Giacalone, e Parajuly (2017); Franco (2017); Jugend *et al*. (2020); Khan e Haleem (2021); Moreno *et al*. (2016); Oliveira *et al*. (2016); Sumter *et al*. (2020); Vihma e Moora (2020); Wang, Burke, e Zhang (2022)
	Business models: offering products as a service	Asif *et al*. (2021); Bocken *et al*. (2016); Boorsma *et al*. (2022); Bressanelli *et al*. (2020); Dokter, Thuvander, e Rahe (2021); Franco (2017); Jugend *et al*. (2020); Moreno *et al*. (2016); Rios e Charnley (2017); Shahbazi e Jönbrink (2020); Sumter *et al*. (2020); Sumter *et al*. (2021); Wang, Burke, e Zhang (2022)
	Modularity facilitates successful repair behavior	Amend *et al*. (2022); Asif *et al*. (2021); Bocken *et al*. (2016); Bressanelli *et al*. (2020); Chouinard *et al*. (2019); Cordella *et al*. (2021); Dokter, Thuvander e Rahe (2021); Hollander, Bakker e Hultink (2017); Joustra, Flipsen, e Balkenende (2021); Mesa, Esparragoza, e Maury (2018); Moreno *et al*. (2016); Oliveira *et al*. (2016); Pamminger, Glaser e Wimmer (2021); Shahbazi, Johansen e Sundin (2021); Sumter *et al*. (2020); Sumter *et al*. (2021)
	Cleaner production	Batwara *et al*. (2022); Evrard *et al*. (2021); Fernando *et al*. (2021); Huertas *et al*. (2013); Khan e Haleem (2021); Ko (2020); Ofterdinger, Dlugoborskyte e Herstatt (2021); Oliveira *et al*. (2016); Ortner, Tay, e Wortmann (2022); Pérez-Ortega *et al*. (2021); Pigosso, Rozenfeld, e McAloone (2013); Sousa-Zomer *et al*. (2018); Sumter *et al*. (2020); Sumter *et al*. (2021); Tao *et al*. (2017); Urbinati, Chiaroni, e Toletti (2019); Vinodh *et al*. (2017)
	Reduce environmental impact	Almeida, Borsato, e Ugaya (2017); Batwara *et al*. (2022); Bovea e Pérez-Belis (2012); Bressanelli *et al*. (2020); Chouinard *et al*. (2019); Desing, Braun, e Hischier (2021); Diaz *et al*. (2021); Evrard *et al*. (2021); Fernando *et al*. (2021); He *et al*. (2021); Hollander, Bakker, e Hultink (2017); Huertas *et al*. (2013); Jensen *et al*. (2019); Jugend *et al*. (2020); Khan e Haleem (2021); Ko (2020); Lama *et al*. (2022); Laurenti *et al*. (2015); Lin (2018); Loon, Diener, e Harris (2021); Mestre e Cooper (2017); Ofterdinger, Dlugoborskyte, e Herstatt (2021); Ortner, Tay, e Wortmann (2022); Pamminger, Glaser, e Wimmer (2021); Pérez-Ortega *et al*. (2021); Pigosso, Rozenfeld, e McAloone (2013); Rios e Charnley (2017); Sauerwein *et al*. (2019); Shahbazi e Jönbrink (2020); Sihvonen e Partanen (2016); Sousa-Zomer *et al*. (2018); Spreafico (2022); Sumter *et al*. (2020); Sumter *et al*. (2021); Urbinati, Chiaroni, e Toletti (2019); Vimal *et al*. (2022); Vinodh e Rathod (2010); Vinodh *et al*. (2017)
	Industrial symbiosis	Khan e Haleem (2021); Moreno *et al*. (2016); Sumter *et al*. (2021); Vihma e Moora (2020); Wang, Burke, e Zhang (2022)
	Use of recycled and recyclable materials	Almeida, Borsato, e Ugaya (2017); Ameli, Mansour, e Ahmadi-Javid (2019); Batwara *et al*. (2022); Bocken *et al*. (2016); Cong, Zhao, e Sutherland (2019); Fernando *et al*. (2021); Ford e Fisher (2019); He *et al*. (2021); Jugend *et al*. (2020); Ko (2020); Laurenti *et al*. (2015); Leal *et al*. (2020); Oliveira *et al*. (2016); Pérez-Ortega *et al*. (2021); Sauerwein *et al*. (2019); Shahbazi, Johansen, e Sundin (2021); Sousa-Zomer *et al*. (2018); Tao *et al*. (2017); Urbinati, Chiaroni, e Toletti (2019); Vimal *et al*. (2022)

Quadro 5: Classificação dos autores segundo os benefícios da EC apresentados – Parte 1

Stakeholders	Benefícios	Autores
Recycling	Ease of recycling due to proper material selection	Almeida, Borsato e Ugaya (2017); Ameli, Mansour e Ahmadi-Javid (2019); Bocken *et al.* (2016); Bressanelli *et al.* (2020); Cong, Zhao, e Sutherland (2019); Franco (2017); Gagnon *et al.* (2022); Huertas *et al.* (2013); Jugend *et al.* (2020); Khan e Haleem (2021); Laurenti *et al.* (2015); Leal *et al.* (2020); Oliveira *et al.* (2016); Pérez-Ortega *et al.* (2021); Shahbazi e Jönbrink (2020); Sousa-Zomer *et al.* (2018); Tao *et al.* (2017); Urbinati, Chiaroni, e Toletti (2019)
Remanufacturing	Greater utilization of returned materials	Almeida, Borsato e Ugaya (2017); Boorsma *et al.* (2022); Bressanelli *et al.* (2020); Chouinard *et al.* (2019); Evrard *et al.* (2021); Ford e Fisher (2019); Gagnon *et al.* (2022); Jensen *et al.* (2019); Khan e Haleem (2021); Laurenti *et al.* (2015); Loon, Diener, e Harris (2021); Moreno *et al.* (2016); Pamminger, Glaser, e Wimmer (2021); Shahbazi e Jönbrink (2020); Sousa-Zomer *et al.* (2018); Zikopoulos (2022)
	Higher number of units remaining in operation over two periods	Asif *et al.* (2021); Dokter, Thuvander e Rahe (2021); Evrard *et al.* (2021); Jensen *et al.* (2019); Joustra, Flipsen, e Balkenende (2021); Jugend *et al.* (2020); Shahbazi, Johansen, e Sundin (2021); Sousa-Zomer *et al.* (2018); Sumter *et al.* (2020); Zikopoulos (2022)
	Lower material consumption per product user	Chouinard *et al.* (2019); Evrard *et al.* (2021); Jensen *et al.* (2019); Laurenti *et al.* (2015); Loon, Diener, e Harris (2021); Pamminger, Glaser, e Wimmer (2021); Shahbazi, Johansen, e Sundin (2021); Sumter *et al.* (2020); Wang, Burke, e Zhang (2022); Zikopoulos (2022)
Repair	Self-repair or repair by a professional service is very high, particularly when the device is a modular smartphone	Amend *et al.* (2022); Bocken *et al.* (2016); Cordella *et al.* (2021); Dokter, Thuvander e Rahe (2021); Hollander, Bakker e Hultink (2017); Moreno *et al.* (2016); Shahbazi, Johansen e Sundin (2021)
	Extension of product lifespan through repairs	Almeida, Borsato e Ugaya (2017); Asif *et al.* (2021); Bocken *et al.* (2016); Bressanelli *et al.* (2020); Chouinard *et al.* (2019); Cordella *et al.* (2021); Dokter, Thuvander e Rahe (2021); Evrard *et al.* (2021); Hollander, Bakker, e Hultink (2017); Joustra *et al.* (2022); Joustra, Flipsen, e Balkenende (2021); Jugend *et al.* (2020); Khan e Haleem (2021); Loon, Diener e Harris (2021); Moreno *et al.* (2016); Ofterdinger, Dlugoborskyte e Herstatt (2021); Pamminger, Glaser e Wimmer (2021); Shahbazi e Jönbrink (2020); Shahbazi, Johansen e Sundin (2021); Sumter *et al.* (2020); Sumter *et al.* (2021)

Table 6: Classification of Authors According to the Benefits of the Circular Economy Presented – Part 2
Source: Prepared by the author

In addition to benefits, the Circular Economy (CE) also presents barriers, which are discussed in Section 2.1.8.

2.1.8 Barriers to the Circular Economy

Although many business and political sectors have proclaimed their support for the Circular Economy (CE), its implementation still appears to be at an early stage. Limited progress in implementing the CE can be attributed to a variety of barriers (Kirchherr et al., 2018).

According to Kirchherr et al. (2018), the barriers to implementing the CE may be cultural, market-related, regulatory, and technological.

The cultural barrier can be understood as the lack of awareness and/or willingness to engage with the CE. According to Cordella et al. (2021), Kirchherr et al. (2018), and Vihma and Moora (2020), the following situations may be associated with cultural barriers:

- Companies are accustomed to operating within a linear system;
- Limited willingness to collaborate along the value chain, as not all companies are willing to cooperate with each other;
- Lack of consumer awareness and interest;
- Employee hesitation due to company culture.

The market barrier may be related to the lack of economic viability of circular business models. According to Bressanelli et al. (2020), Hapuwatte and Jawahir (2021), and Kirchherr et al. (2018), the following situations may be associated with market barriers:

- The purchase of virgin materials has a low cost, which may hinder the use of recycled materials;
- A high investment is required to implement CE practices, resulting in high initial costs;
- Lack of standardization for circular models, requiring new learning processes before standardization can occur;
- Difficulty in obtaining financing for the implementation of circular business models.

The regulatory barrier may be related to the lack of policies supporting the transition from a linear economy to the CE. Khan and Haleem (2021), Kirchherr et al.

(2018), and Wang, Burke, and Zhang (2022) highlight the following situations associated with regulatory barriers:

- The purchase of circular products is limited because most consumers focus only on cost rather than sustainability;
- Lack of global consensus, since companies operate internationally and require a high level of alignment that is difficult to achieve;
- Lack of legislation and governmental decisions supporting the CE.

The technological barrier can be understood as the lack of technologies necessary to implement CE practices. According to Chouinard et al. (2019), Kirchherr et al. (2018), and Sumter et al. (2021), the following situations may be associated with technological barriers:

- Limited application of new business models;
- Lack of capability to ensure high quality in remanufactured products;
- Lack of data, such as environmental impact data for some materials used in products;
- Products are not designed for circular business models;
- Limited availability and quality of recycled materials.

Amend et al. (2022) conducted a study addressing smartphones that may face difficulties in the repair process, such as the unavailability of spare parts, repair tools, repair manuals, the cost of spare parts, the time required, or the complexity of repairs.

According to Diaz, Reyes, and Baumgartner (2022), some companies demonstrate weak intentions regarding sustainability. These companies do not view CE implementation as a strategy for product value retention but rather as a means to comply with legal requirements. Other companies consider extending product life through repair solely as a market opportunity rather than adopting the broader CE principles described in CE definitions and frameworks. Another barrier mentioned by these authors is related to information management systems. Managers in this area must be actively involved in implementing CE and value retention strategies efficiently, since they manage organizational information flows that connect vertical and horizontal structures. Financial barriers are also highlighted, as implementing CE strategies requires substantial investment.

Gagnon et al. (2022) emphasize that the main barriers identified in Canada include lack of awareness and demand, higher costs, lack of harmonized policies, isolated approaches, and gaps in innovation and technology. In the case of construction materials, significant barriers were identified for implementing promising strategies. For wood, large-scale recovery is almost impossible because buildings are not designed for deconstruction and dismantling. For particleboard, the use of resins and laminates limits energy recovery possibilities.

Based on expert recommendations, Gagnon et al. (2022) propose accelerating the implementation of CE strategies for forest products. This requires different policy readiness levels in the construction and packaging sectors. Bringing together relevant stakeholders to establish a common understanding of circularity in the construction sector, along with targeted support for technologies that enable dismantling and deconstruction, are key steps for adopting circular practices. In the packaging sector, existing policy frameworks need to be refined and expanded alongside investments in waste management infrastructure to promote material recovery and reintegration into manufacturing processes.

Joustra et al. (2022) conducted case studies that revealed significant potential for redesign. These studies were part of an innovation project encouraging participants to explore circular product design alongside circular business models. However, a major challenge was identified due to existing recovery and reprocessing infrastructure, particularly in large sectors such as the automotive industry. These systems are typically configured in a linear rather than circular manner, limiting the adoption of circular design strategies. Therefore, CE implementation possibilities are constrained by existing business structures, logistics systems, reprocessing technologies, and political contexts.

Nag, Sharma, and Kumar (2022) identify three barriers to CE implementation. The first concerns product standardization, which is deeply embedded in the linear system and must be re-learned and re-standardized for circular systems. The second barrier relates to product obsolescence, which may occur rapidly in some sectors, leading consumers to reject outdated products or making repairs impossible due to unavailable components. The third barrier concerns business model innovation, as circular systems require investments in innovation.

Okumura (2022) states that the greater the reuse of end-of-life products, the higher the probability that reused products may fail compared with newly manufactured products. This may represent a barrier both for companies considering investment in repair and for consumers.

Zikopoulos (2022) highlights two barriers affecting companies implementing the CE. One is related to consumer environmental awareness, as consumers often fail to recognize the socio-environmental benefits of circular products. The other barrier is related to government intervention, where companies focus more on financial aspects rather than promoting sustainable production.

Dokter, Thuvander, and Rahe (2021) report that designing products for circularity is a challenge because it requires addressing multiple product life cycles and collaboration among various stakeholders to optimize resources and processes. Another challenge involves the lack of regulations and policies supporting circularity and stricter regulations regarding environmental impact calculations for design solutions.

Evrard et al. (2021) present the concept of “immortal products,” which are designed to last a long time and can be repaired or upgraded to extend their life cycle. However, this concept may also present challenges. Because they use older technologies, such products may be more polluting than newer technologies when considering everyday use. Consumer acceptance may decline over time due to aesthetic differences compared with newer products, making them less desirable despite functional updates. Additionally, increasing repair or remanufacturing activities over time may become costly and difficult to maintain with outdated technologies.

Fernando et al. (2021) emphasize that in developing countries such as Malaysia, government support plays a critical role in fostering industrial development. Their results show that government regulations directly affect the performance of recycled products but do not necessarily affect their competitiveness. Governments also promote innovative local products globally, although product competitiveness ultimately depends on global market preferences.

According to He et al. (2021), the connection between components and parts directly affects vehicle recyclability at end of life. Materials that could otherwise be recyclable may become difficult or impossible to recycle because they are bonded with adhesives or welded with other materials that are difficult to separate. Additionally, new dismantling methods are required for electric vehicles, which contain various valuable components in batteries, motors, and power electronics. These deficiencies reduce the recycling value of end-of-life vehicles.

Jiang et al. (2021) highlight that companies are beginning to incorporate corporate sustainability into their strategic vision. This gradually increases sustainability awareness among designers, helping them identify more relevant research and eventually produce more sustainable products and processes.

Joustra, Flipsen, and Balkenende (2021) point out that many strategies focus on extending product life and preserving resources but do not explicitly consider safety issues related to composite materials. Risks may arise throughout the life cycle of composite products, including the release of volatile organic compounds, fibers, particles, and dust, which pose threats to human health and the environment. Additionally, reprocessing processes that separate or reduce the size of materials may lead to hazardous emissions. Therefore, beyond preserving resources, additional measures are necessary to address human, environmental, and ecological impacts.

Material contamination during recycling remains another challenge. Undesirable mixtures complicate reprocessing, since most recycling processes require well-defined material inputs to produce high-quality recyclates. For reuse processes, mixing different materials should be avoided to prevent complications in future material recovery (Joustra, Flipsen, & Balkenende, 2021).

Khan and Haleem (2021) suggest that there is still limited awareness among consumers and supply chain partners regarding circular practices. Therefore, awareness campaigns and promotional initiatives are necessary to promote the CE concept. Designing products for circularity is a high-priority practice that requires investment in research and design. In this context, government incentives and financial support can facilitate CE adoption. Cultural and regional biases among experts were also identified as barriers.

Loon, Diener, and Harris (2021) criticize the assumption in many studies that the world remains static when circular products are introduced, ignoring possible impacts on consumption. When considering circular business models, functions rather than products should become the unit of analysis, implying the need to include potential changes in consumption behavior. Broader environmental impacts should also be assessed, including reverse transport, non-reusable items, improvements or degradation in energy efficiency, and rebound effects. There are also challenges in implementing product design strategies for CE, such as modularity, upgradability, and repairability. Similarly, the effects of circular business models on consumption have not yet been fully incorporated into environmental assessments.

According to Ofterdinger, Dlugoborskyte, and Herstatt (2021), it is difficult to find circular materials that can effectively replace traditional raw materials. For example, plastic may be replaced with composite materials, but questions remain regarding whether these alternatives provide the same appearance, barrier properties, and shelf-life characteristics. Another challenge involves waste streams, as paper and plastic recycling streams are often contaminated with waste.

Leal et al. (2020) identify several difficulties in implementing the CE, including:

- Difficulty in obtaining detailed end-of-life product information required to apply indicators;
- The need to constantly update data used to assess material compatibility and recyclability to reflect real recycling chain conditions;
- Difficulty in evaluating the use of recycled materials considering technical, economic, and environmental aspects;
- Limited access to information, especially environmental data, about materials used;
- Technical, economic, and environmental data used for evaluating indicators must be continuously updated;
- The convenience of using recycled materials may change over time and cannot rely on a single evaluation;
- Economic convenience may fluctuate due to variations in resource availability, such as metals;
- Evaluations may not consider the economic or environmental impacts across total production, where small cost reductions can result in significant benefits when applied at scale.

As was done for the benefits, a table was developed containing 28 barriers or challenges classified into six categories related to the implementation of the Circular Economy in product development. These categories are: Government, Organization, Repair, Recycling, Reuse, and Society. Table 6 presents several authors who identified these barriers in their studies, grouped according to the corresponding category.

Stakeholders	Barriers	Authors
Government	Lack of supporting policies	Khan e Haleem (2021); Mestre and Cooper (2017); Moreno *et al.* (2016); Urbinati, Chiaroni, e Toletti (2019); Vihma e Moora (2020)
	Government intervention	Fernando *et al.* (2021); Mestre e Cooper (2017); Zikopoulos (2022)
	Limitations due to political issues	Dokter, Thuvander, e Rahe (2021); Gagnon *et al.* (2022); Joustra *et al.* (2022); Jugend *et al.* (2020); Laurenti *et al.* (2015); Moreno *et al.* (2016); Sumter *et al.* (2021); Wang, Burke, e Zhang (2022)
Organization	Financial barriers	Bressanelli *et al.* (2020); Diaz, Reyes, e Baumgartner (2022); Gagnon et. al (2022); Sumter *et al.* (2021); Urbinati, Chiaroni, e Toletti (2019); Vihma e Moora (2020)
	Organizational culture	Bovea e Pérez-Belis (2012); Chouinard *et al.* (2019); Dokter, Thuvander e Rahe (2021); Jiang *et al.* (2021); Khan e Haleem (2021); Mestre e Cooper (2017); Pigosso, Rozenfeld, e McAloone (2013); Sousa-Zomer *et al.* (2018); Urbinati, Chiaroni, e Toletti (2019); Vihma e Moora (2020)
	High costs	Gagnon *et al.* (2022); Urbinati, Chiaroni, e Toletti (2019)
	Difficulty in designing for circularity	Almeida, Borsato e Ugaya (2017); Bovea e Pérez-Belis (2012); Chouinard *et al.* (2019); Dokter, Thuvander e Rahe (2021); Hollander, Bakker e Hultink (2017); Ko (2020); Mohagheghian *et al.* (2021); Tao *et al.* (2017)
	Difficulty in achieving product modularity	Loon, Diener, e Harris (2021); Mesa, Esparragoza, e Maury (2018); Sauerwein *et al.* (2019); Tao *et al.* (2017)
	Difficulty in using recycled materials	Hollander, Bakker, e Hultink (2017); Leal *et al.* (2020)
	Business model innovation	Franco (2017); Jensen *et al.* (2019); Moreno *et al.* (2016); Nag, Sharma e Kumar (2022)
	Infrastructure and technology limitations	Almeida, Borsato, e Ugaya (2017); Bocken *et al.* (2016); Ford e Fisher (2019); Gagnon *et al.* (2022); Huertas *et al.* (2013); Joustra *et al.* (2022); Jugend *et al.* (2020); Khan e Haleem (2021); Laurenti *et al.* (2015); Loon, Diener, e Harris (2021); Mestre e Cooper (2017); Moreno *et al.* (2016); Pigosso, Rozenfeld, e McAloone (2013); Sumter *et al.* (2021); Tao *et al.* (2017); Urbinati, Chiaroni, e Toletti (2019); Vihma e Moora (2020); Wang, Burke, e Zhang (2022)
	Limitations in information management systems	Diaz *et al.* (2021); Huertas *et al.* (2013); Mesa, Esparragoza e Maury (2018); Mohagheghian *et al.* (2021)
	Logistics and supply chain challenges	Almeida, Borsato e Ugaya (2017); Bocken *et al.* (2016); Franco (2017); Huertas *et al.* (2013); Joustra *et al.* (2022); Jugend *et al.* (2020); Khan e Haleem (2021); Loon, Diener e Harris (2021); Sumter *et al.* (2021); Urbinati, Chiaroni, e Toletti (2019); Wang, Burke, e Zhang (2022)
	Need to comply with legal requirements	Asif *et al.* (2021); Chouinard *et al.* (2019); Diaz, Reyes, e Baumgartner (2022); Sumter *et al.* (2021); Wang, Burke, e Zhang (2022)
	Product obsolescence	Chouinard *et al.* (2019); Leal *et al.* (2020); Nag, Sharma, e Kumar (2022)
	Standardization of products and processes	Hapuwatte e Jawahir (2021); Huertas *et al.* (2013); Jiang *et al.* (2021); Nag, Sharma, e Kumar (2022); Ofterdinger, Dlugoborskyte, e Herstatt (2021); Pigosso, Rozenfeld, e McAloone (2013); Sauerwein *et al.* (2019); Tao *et al.* (2017)
	Long-lasting products may use outdated technologies	Evrard *et al.* (2021); Hollander, Bakker, e Hultink (2017)
	Repair viewed only as a market opportunity	Asif *et al.* (2021); Diaz, Reyes, e Baumgartner (2022); Jensen *et al.* (2019); Shahbazi, Johansen, e Sundin (2021)

Table 7: Classification of Authors According to the Barriers to the Circular Economy Presented – Part 1

Stakeholders	Barriers	Authors
Recycling	Undesirable mixing complicates reprocessing	He *et al.* (2021); Joustra, Flipsen, e Balkenende (2021); Leal *et al.* (2020)
	Competitiveness of a recycled product depends on global market preferences	Fernando *et al.* (2021); Ford e Fisher (2019)
	Contamination of materials such as paper and plastic	Joustra, Flipsen, e Balkenende (2021); Ofterdinger, Dlugoborskyte, e Herstatt (2021)
	Difficulty in disassembly and separation	Bressanelli *et al.* (2020); He *et al.* (2021); Sauerwein *et al.* (2019); Vanegas *et al.* (2018)
Repair	Difficulty in disassembly	Bressanelli *et al.* (2020); Gagnon *et al.* (2022); He *et al.* (2021); Vanegas *et al.* (2018)
	Unavailability of spare parts, repair tools, repair manuals, the cost of spare parts, the time required, or the complexity of the repair	Amend *et al.* (2022); Mohagheghian *et al.* (2021); Sauerwein *et al.* (2019)
Reuse	Difficulty in reuse due to the process used	Gagnon et al, (2022); Shahbazi, Johansen, e Sundin (2021)
	The greater the reuse of an end-of-life product, the higher the probability that the reused product will fail compared to a newly manufactured product	Desing, Braun, e Hischier (2021); Hollander, Bakker, e Hultink (2017); Joustra, Flipsen, e Balkenende (2021); Okumura (2022)
Society	Improve consumers' environmental awareness	Atlason, Giacalone, e Parajuly (2017); Cordella *et al.* (2021); Ford e Fisher (2019); Gagnon *et al.* (2022); Jugend *et al.* (2020); Khan e Haleem (2021); Laurenti *et al.* (2015); Loon, Diener, e Harris (2021); Mesa, Esparragoza, e Maury (2018); Mestre e Cooper (2017); Sousa-Zomer *et al.* (2018); Urbinati, Chiaroni, e Toletti (2019); Wang, Burke, e Zhang (2022); Zikopoulos (2022)
	Products designed to last a very long time may face challenges when compared with newer products	Desing, Braun, e Hischier (2021); Evrard *et al.* (2021); Hollander, Bakker, e Hultink (2017); Pamminger, Glaser, e Wimmer (2021)

Table 8: Classification of Authors According to the Barriers to the Circular Economy Presented – Part 2

With the presentation of the barriers, the section on the Circular Economy (CE) is concluded, and the Product Development Process (PDP) is analyzed next, whose concepts are presented in Section 2.2.

2.2 Product Development Process

The Product Development Process (PDP) can be defined as a series of activities capable of transforming technological and market information into products or services, following the company's strategy (Rozenfeld et al., 2006).

Product development is a set of activities that enables companies to address three important factors for business success: customer relationships, operational excellence, and product leadership (Vieira, Bouras, & Debaecker, 2013).

Romeiro Filho et al. (2010) state that the PDP is a multidisciplinary process that requires cooperation among marketing, research and development (R&D), and operations (manufacturing). The PDP can be considered a business process with inputs—such as engineering hours, knowledge, standards, and regulations—that are processed in order to generate outputs, such as prototypes and products launched in the market (Romeiro Filho et al., 2010).

Baxter (2000, p. 2) states that:

> "New product development is a complex activity involving diverse interests and skills: consumers want novelty and better products at reasonable prices; salespeople seek differentiation and competitive advantages; production engineers desire simplicity in manufacturing and ease of assembly; designers wish to experiment with new materials, processes, and formal solutions; and entrepreneurs want low investment and a rapid return on capital. Therefore, new product development is necessarily a compromise solution. Different types of interests must be satisfied" (Baxter, 2000, p. 2).

Dias (2019) states that the PDP is related to strategic planning, market monitoring, sales, meeting customer needs, research and development, distribution, supply management, production, and technical support.

Product development is a critical component of all business operations. In recent years, with advances in technology and increasing public awareness regarding environmental protection, product development processes (PDPs) in supply chains need to be environmentally sustainable (Fung et al., 2021).

Choi et al. (2021) emphasize that new product development is risky and its successful outcome is uncertain in the short term. Nevertheless, product development is critical for the sustainable growth of companies, since most corporate sales come from newly introduced products in the market.

The new product development process within a company is often described through an analytical model for innovation processes and represents the business process through which a company delivers innovation to the market (Choi et al., 2021; Cantamessa & Montagna, 2016).

Contemporary PDP models distinguish the pre-project phase, which analyzes market conditions and is associated with the company's strategy; the project phase; and the post-project phase, which includes product monitoring and withdrawal from the market. Therefore, these models cover the entire product life cycle. The idea of using knowledge domains from companies and customers to describe the capability to create successful products or services has frequently been discussed in publications on this topic (Urban, Łukaszewicz, & Krawczyk-Dembicka, 2020; Dalenogare et al., 2018; Liao et al., 2017; Kagermann et al., 2013).

Given the concept of the PDP, Section 2.2.1 presents some PDP models.

2.2.1 Product Development Process Models

Rozenfeld et al. (2006, p. 32) state that:

> "Product development must be an effective and efficient process in order to truly fulfill its mission of enhancing a company's competitiveness. The formalization of a management model and the structuring of the product development process enable all those involved—top management, personnel from the company's functional areas, and partners—to share a common understanding of this process: what results are expected from the PDP, what activities must be performed and how they should be carried out, the conditions to be met, the valid sources of information, and the decision criteria to be adopted (Rozenfeld et al., 2006, p. 32).

Reference models describe the Product Development Process (PDP), and their purpose is to serve as a reference so that product development carried out by companies and their professionals can occur according to a common perspective. With a reference model, it is possible to obtain a unified view of the PDP, allowing the alignment of knowledge among all participants involved in a specific development project (Rozenfeld et al., 2006).

There is no single model for the PDP, as several authors propose their own models.

The Stage-Gate model, proposed by Cooper (1990), represents a new product management system designed to address the fundamental challenges of the innovation process. These challenges include the need to access relevant information and to manage a variety of alternatives for decision-making.

The PDP is based on process management approaches. According to Cooper, in a production process the product moves through several workstations, known as stages, where material transformations occur. Between each stage, quality control checkpoints called gates are inserted, where the product quality is evaluated and a decision is made whether the product should proceed to the next workstation or be rejected (Cooper, 1990).

According to Cooper (2008), each phase of the system is designed to generate documents and information intended to support decision-making at the gates. The idea is that, as the product progresses through the process, more information is acquired—especially regarding costs, development progress, and probability of success—while investments in development increase. Therefore, this system seeks to minimize resource waste by evaluating the feasibility of developments from the beginning of planning through to completion, supported by the continuous generation of documents and information.

The Stage-Gate model therefore aims to encompass all phases of product development. In its standard configuration, as illustrated in Figure 5, the system divides the innovation process into five stages of work. Between each stage there is a gate or decision point, where the decision is made whether to continue or terminate the project (Cooper, 2008).

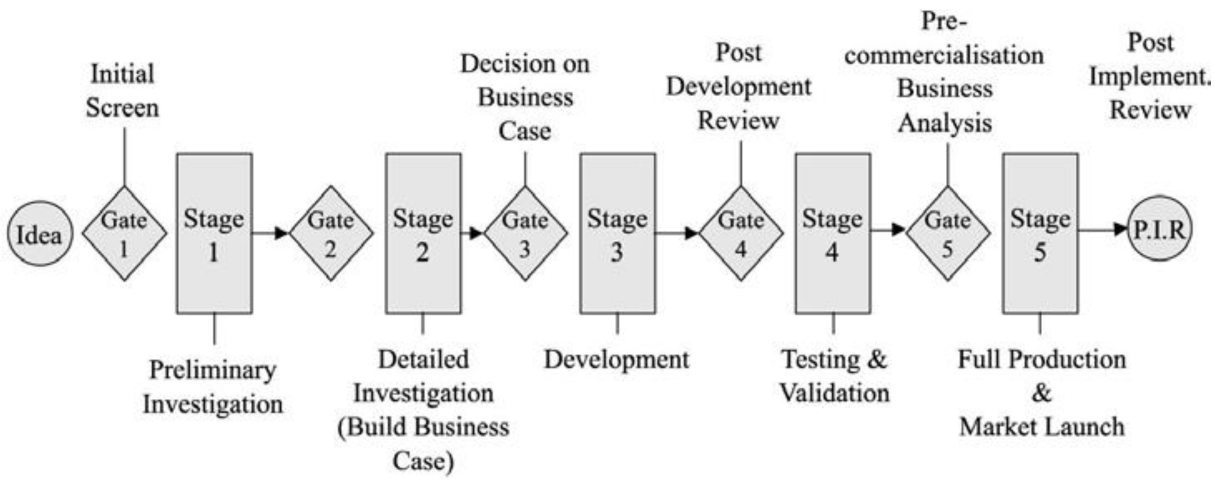

Figure 5: Stage-Gate Model Proposed by Cooper
Source: Adapted from Cooper (2008)

The standard model established by Cooper (1990) conceptualizes the innovation process as beginning with the discovery or conception of a product and culminating in the post-launch review. The author proposes specific deliverables for each phase of development:

- **Stage 1 – Scoping:** conducting a preliminary market analysis to determine the size and potential of the market, as well as the likely acceptance of the new product. In addition, a preliminary technical analysis is performed to verify the technical feasibility and project timeline.
- **Stage 2 – Business Case:** conducting a market study to identify consumer needs, desires, and preferences. Concept tests are performed to evaluate consumer acceptance of the new product. Customer needs and desires are translated into technically and economically viable solutions, including preliminary design studies and prototype construction. A detailed economic analysis is prepared, covering cash flow and sensitivity analyses. This is the main stage of the model, as it defines the economic feasibility of the product to be developed.
- **Stage 3 – Development:** product development is carried out, including detailed functionality testing, preparation of marketing and operations plans, and updating of the economic analysis.
- **Stage 4 – Testing and Validation:** conducting product quality and performance tests, user testing to verify functionality and consumer reactions, pilot production to test and refine the production process, determine precise costs and production speed, and market testing or trial sales to measure the effectiveness of the marketing plan and forecast the project's financial return. The economic analysis is revised to validate economic feasibility based on updated cost and return information.
- **Stage 5 – Launch:** implementation of the marketing and operational launch plans.

Rozenfeld et al. (2006) present a PDP model divided into three macro-phases, as shown in Figure 6.

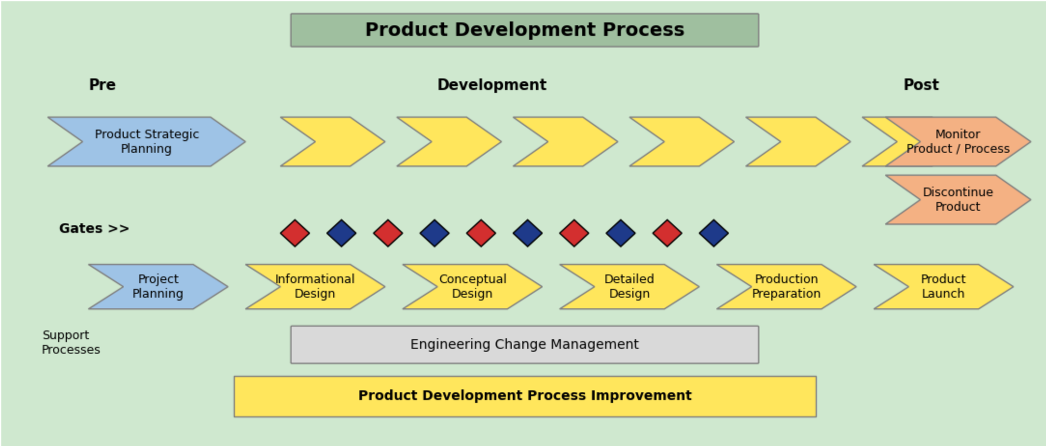

Figure 6: PDP Model Proposed by Rozenfeld
Source: Adapted from Rozenfeld et al. (2006)

The pre-development macro-phase must establish the strategic direction; therefore, the company's Strategic Planning is defined, incorporating the ideas of all stakeholders involved with the products. Based on this, the portfolio of projects to be developed is prepared (Rozenfeld et al., 2006).

Rozenfeld et al. (2006) highlight that the pre-development macro-phase involves:

- The definition of the development project;
- The delimitation of resource constraints;
- Knowledge and information about consumers;
- Identification of technological and market trends.

The first step of the pre-development macro-phase is the unfolding of the results of strategic planning into a portfolio, or project portfolio. It concludes with the Scope Statement and the initial Project Plan for one of the products included in the project portfolio, which will then be developed in the subsequent stages (Rozenfeld et al., 2006).

The development macro-phase consists of activities aimed at developing the projects defined and approved in the previous phase. In this macro-phase, each product is managed as a project. During this phase, manufacturing and assembly processes are also defined, which strongly influence the final cost of the product (Rozenfeld et al., 2006).

The post-development macro-phase consists of the systematic withdrawal of the product from the market and an evaluation of the entire product life cycle, with the objective of using the experiences gained during development as references for future cases (Rozenfeld et al., 2006).

In summary, Rozenfeld et al. (2006) state that the PDP is divided into the following phases: Project planning; Informational design; Conceptual design; Detailed design; Production preparation; Product launch; Product follow-up and discontinuation. The model proposed by Rozenfeld et al. (2006) does not directly focus on the circular economy approach, which may be considered its main weakness.

Lin (2018) proposes a product design approach based on user experience from a people-oriented perspective. To understand users' preferences regarding products, it was necessary to focus on the main product factors and the crucial characteristics of users. Information systems for decision-making were employed to identify user experience in the design of products and services, in order to provide useful information for intelligent production.

Lin (2018) used the product development model presented in Figure 7.

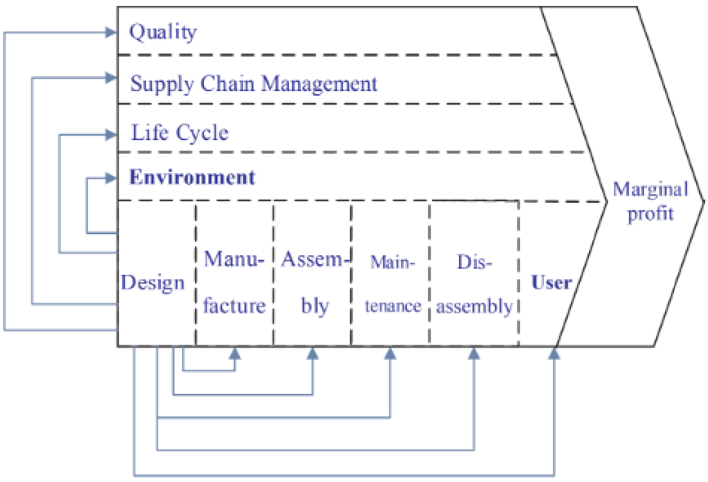

Figure 7: Product Design and Development
Source: Lin (2018)

Considering Figure 7, Lin (2018) highlights that rapid changes in the market and product diversification have shifted product design from a production-oriented approach to a market-oriented approach. This shift aims to better meet market and customer needs while maintaining a focus on an environmentally oriented dimension that takes into account environmental and user-related factors, strengthens product design quality, and promotes the exploration of sustainable development. From the model proposed in Figure 7, Lin (2018) highlights the following points:

- Design for manufacturing: considering that manufacturing design helps save resources in the product manufacturing process and enables faster and higher-quality production.
- Design for assembly: considering that assembly design helps increase efficiency and reduce wear in the product assembly process.
- Design for disassembly: considering that disassembly design allows a product to be quickly dismantled, thereby reducing waste and the use of consumables.
  • Design for users: considering that user experience in design helps improve product experience and enhance user satisfaction.
- Design for quality: considering that design quality helps increase product performance in order to meet customer needs.
- Design for supply chain management: considering supply chain factors in design helps increase product efficiency within the supply chain and reduce instability.
  • Design for the life cycle: considering the product life cycle in design helps evaluate the overall resources consumed and the pollution generated throughout the product life cycle.
- Design for the environment: considering the environmental impact of a product during the design phase helps achieve sustainability goals.

Lin (2018) proposes a product design approach based on user experience using a data-driven innovation framework and follows the systematic steps shown in Figure 8. The model considers both user needs (user experience and satisfaction) and industry requirements.

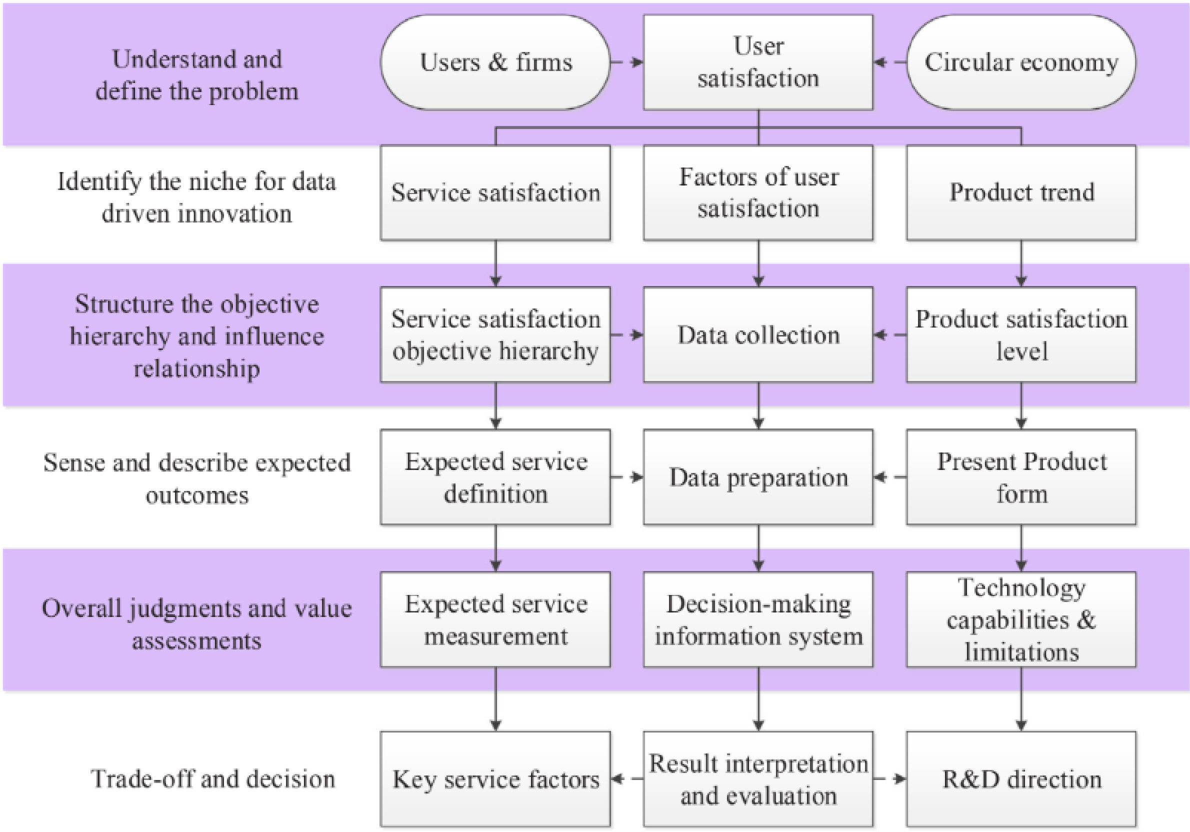

Figure 8: User Experience–Based Product Design Approach
Source: Lin (2018)

Lin (2018) divides the model into six stages, namely:

- Understanding and defining the problem: in this stage of product development, an appropriate service design direction is identified based on the resources of the company and its partners, so that the most up-to-date service can be launched to meet user expectations most of the time.
- Identifying the niche for data-driven innovation: service experience includes subjective activities, behaviors, opinions, feelings, personalities, and physiological responses. Input, process, and output factors influence users' emotional reactions and behavioral tendencies toward the product. By using information systems, sensors, and Internet of Things technologies, large datasets (big data) on user behavior can be collected automatically or semi-automatically.
- Structuring the objective hierarchy and influence relationships: a scenario-based user satisfaction experiment can be conducted to collect data about users, services, and the external environment. Insights about users and information related to their lifestyles and interests can be obtained. Users

are asked to complete a task list and a testing scenario created to collect data about their experiences with the product and their acceptance of the new service, helping to understand their attitudes.

- Detecting and describing expected results: a deeper understanding of the data, including background factors, categories, determinants, user sentiments, and satisfaction—helps reveal insights. Ordinal scales may be used to measure user satisfaction based on stimulating factors and perceived feelings.
- Value judgments and evaluations: companies use data mining and statistical techniques to uncover hidden information in the data, including user satisfaction data that reveal potential factors influencing future service innovation. These factors must be evaluated based on levels of support and confidence and analyzed according to critical rules. Decisions regarding innovation and new services can then be made based on these critical factors. Leveraging both internal and external company resources and identifying technological capabilities and limitations are essential to determine which services are viable for market launch.
- Trade-offs and decision-making: to validate practical results and interpretations, experts may be invited to provide domain knowledge regarding rules derived from data mining and statistical analyses. User insights and satisfaction decisions support service designers in creating new service concepts and identifying service factors. Due to rapid changes in user behavior and market trends, the derived rules provide useful insights for defining the appropriate service life cycle. The user satisfaction model requires occasional replication to provide new directions for innovation and allow continuous knowledge extraction.

In summary, Lin (2018) proposed an Information Technology (IT) system to enable the product development process to be carried out in an integrated and collaborative manner.

Ko (2020) states that when faced with an eco-friendly product design project, designers often struggle to understand the design elements or even determine where to begin.

In the preliminary analysis processes of a product and its conversion into a green product, the three Green DNAs (green technology, green materials, and green manufacturing) must be integrated into the design methodology. This allows designers to easily understand design elements and further develop innovative eco-friendly products (Ko, 2020):

- Green technology: all technologies related to renewable energy and energy conservation fall into the category of green technology, including solar energy, wind energy, hydroelectric power generation, among others. These technologies are the easiest way to demonstrate the effectiveness of green products. Designers are therefore advised to prioritize this green element in product design.
- Green materials: the ecological concept of the 4R (Reduction, Reuse, Recycling, Regeneration), advocated by governmental agencies and private environmental groups, represents the most basic definition of green material properties. Recent advances in green materials include biodegradable materials derived from plant fibers. When discarded into the external environment, these materials decompose through microorganisms under certain temperature and humidity conditions, causing no environmental damage. Designers are therefore encouraged to prioritize biodegradable materials when selecting materials for eco-friendly products.
- Green manufacturing: for aesthetic purposes, products are often painted, coated, or printed to enhance their appearance. Most of these post-processing procedures use organic solvents and generate harmful toxic substances. If these processes are not properly managed, they may cause pollution and environmental damage. Therefore, if designers avoid applying these manufacturing processes for product decoration and finishing whenever possible, the environmental impact of their work can be significantly reduced.

The integration of the three Green DNAs produces complementary design effects. Therefore, a green extension method is proposed for green product design based on extension theory and the three Green DNA concepts. This innovative green design method incorporates the three Green DNA concepts into the analytical process of the extension method. By analyzing and transforming new product matter-element models, designers can integrate the three Green DNAs into innovative product concepts to develop green products. The procedures of this method are presented in Figure 9.

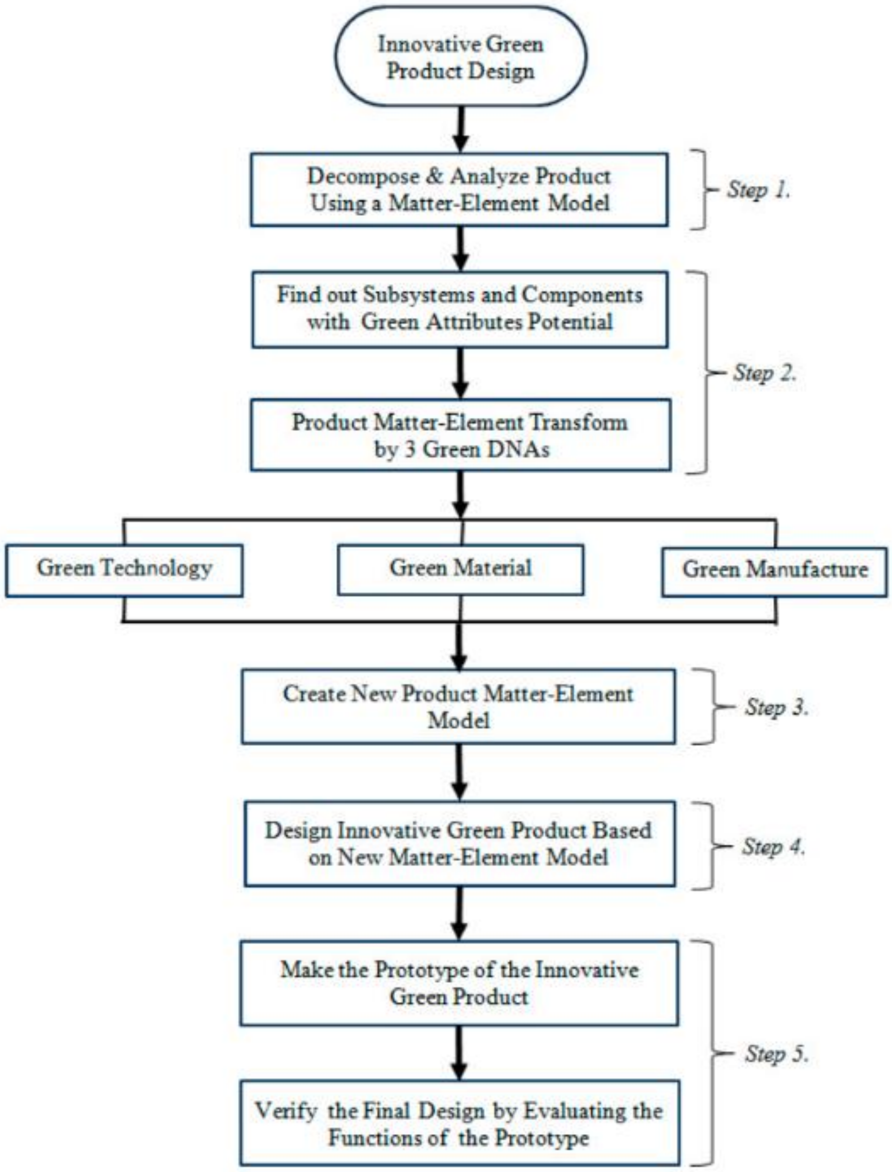

Figure 9: Green Design Method Considering the Three Green DNAs
Source: Ko (2020)

Ko (2020) presents a five-step model:

Step 1: Decompose and analyze the product using the matter-element model. The product is decomposed and analyzed from the system and subsystem levels down to the components in order to obtain complete mechanical and functional information.

Step 2: Identify subsystems or components with innovative green value and opportunities. The three Green DNAs are applied to examine system components and technologies, introducing the concepts of green technology, green materials, and green manufacturing. This enables the adoption of different approaches to achieve eco-design objectives.

Step 3: Apply matter-element transformation to establish a new matter-element model. After identifying the subsystems or components to be innovated or improved, a new product architecture is developed through matter-element transformation. This process can generate new functions or operational methods for the product, and even create an innovative eco-design concept that differs significantly from existing products (Ko, 2020).

Step 4: Introduce the new matter-element model into practical product design. Product design is carried out using the new matter-element model that incorporates the Green DNAs. The design focus is placed on integrating industrial design, mechanical design, and product functionality.

Step 5: Develop a product prototype to validate the eco-design concepts. Finally, a prototype is created based on the practical design, which is used to verify the feasibility and effectiveness of the proposed innovative green product design.

Diaz, Reyes and Baumgartner (2022) present insights into the management factors that enable circular product design at different stages of Product Development Process (PDP) activities. Figure 10 provides an overview of the management factors influencing circular product design at different PDP stages and the main interactions among them.

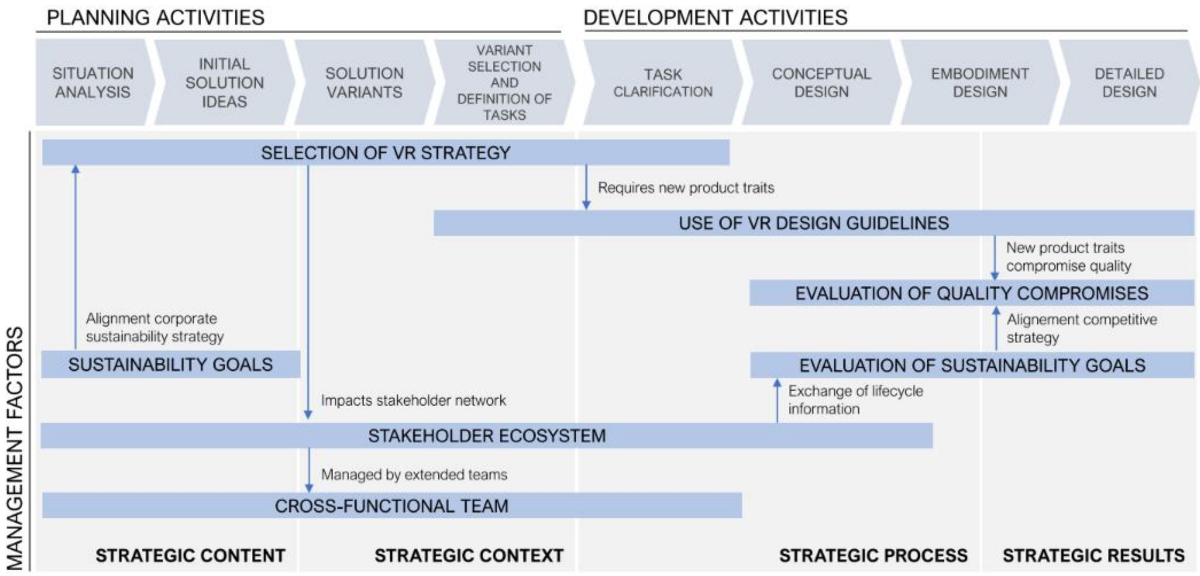

Figure 10: Circular Product Factors in the PDP Phases
Source: Diaz, Reyes and Baumgartner (2022)

The main stages of the model proposed by Diaz, Reyes, and Baumgartner (2022) are as follows:

Selection of value retention strategies: value retention strategies are identified as a subset of competitive strategies. The selection of value retention strategies generally follows situational analysis activities, such as portfolio analysis, product benchmarking, and forecasting. Value retention strategy frameworks provide a general prescription regarding the product life-cycle stage in which they will be implemented, the key actors involved, and the process for recovering value and functionality. It is then the responsibility of companies to translate value retention strategies into new product concepts (as inputs for product idea generation activities and the identification of new product tasks). These strategies therefore need to be addressed relatively early—for example, during product planning activities—so that potential synergies and conflicts of objectives can be identified. A strong degree of integration between product planning and product development activities is also required so that designers can implement the planner's guidelines.

Application of design guidelines: for product planning activities to be carried out by product developers, it is important that a product proposal be available documenting product ideas and describing the main selection criteria along with a preliminary list of design requirements. A value retention strategy is integrated into the product through the formulation of functional requirements derived from value retention. These requirements must then be adopted by developers and translated into design characteristics and operating principles.

Identification of quality trade-offs: the preservation of economic value is linked to the extent to which the product system can perform the functions for which it was designed and to the need for an organization to remain competitive in the market. Therefore, the planning and development team must analyze how new design characteristics, operating principles, and functionalities interact with product quality and determine whether circularity threatens product performance. An appropriate development routine for evaluating this in detail is the product evaluation process. Product evaluations are more elaborate than the initial concept selection conducted during the planning phase because they require decision support that covers a wide range of objectives (task-specific goals, requirements, constraints) and addresses both quantitative and qualitative properties of concept variants. Compliance with value retention strategies can be verified during product evaluation routines through various integrated circularity indicators. In some configurations analyzed, circular economy–related trade-offs were identified concerning quality, aesthetics–modular architecture, reliability of recyclable materials, the product-oriented Product-Service System (PSS) revenue model, ease of maintenance, the results-oriented PSS revenue model, and perceived quality.

Product ecosystem stakeholder analysis: the purpose of this stage is to understand the external strategic context in which the product is embedded. Stakeholder analysis therefore plays a role in planning activities, for example, as part of situational analysis, and also in product/service conceptualization. Product ecosystems have been recognized as important elements for facilitating value delivery within a circular economy. These ecosystems include stakeholders who interact directly with the product as well as those who do not. The main reason for focusing on the first group is that the effectiveness of value retention strategies is largely determined by the actions of such actors. The effect that new product functionalities have on their behavior must therefore be carefully examined. Considering the impact on more indirect stakeholders stems from concerns related to broader strategic design and the potential for sociotechnical transformations. Consequently, companies seeking to fulfill the transformative aspirations of the circular economy and achieve a certain degree of social integration must adopt a medium- and long-term perspective in stakeholder management and aim to influence cultural actors, political actors, regulatory actors, and market actors.

Multifunctional system: the purpose of this activity is to manage operational tasks not directly related to design within an extended multifunctional team. PDP activities are inherently interdisciplinary because they respond to market, environmental, or intraorganizational stimuli. Decisions involve the selection and detailing of new sustainable product ideas, where the capabilities of designers and environmental experts are essential, and also determine whether a product’s financial position or market performance aligns with the company’s competitive strategy. Although the composition of the extended team depends on the company’s specific structure, it generally requires marketing capabilities to ensure a strong understanding of quality requirements, stakeholder management through communication activities, financial capabilities to evaluate product performance, and product management capabilities to conduct risk analyses and feasibility studies. Consequently, multifunctional information management systems, such as product lifecycle management, have been considered effective for integrating information from different departments regarding the product data management platforms used in development. Not only is a horizontal approach to information management necessary, but also a vertical one, since capabilities acquired through seniority are also relevant.

Environmental and social assessment: strong environmental and social performance of products is relevant for corporate sustainability strategies. Within standardized PDP activities, two main decision stages guide the selection of product/service variants in which environmental and social criteria are integrated. These stages are generally referred to as product selection and product evaluation. Product selection is typically conducted at an early stage of development, when product systems incorporate relatively low levels of design detail and performance information is often difficult to quantify.

Interdependencies among factors: based on the observed interdependencies among factors, several management priorities can be derived. First, strong interdependence among factors implies that all of them must be present to some extent. This may require significant resources, which in many cases can negatively affect business profit margins. Therefore, circular product design should be considered a means for companies to achieve competitive advantage rather than merely ensuring that products fulfill new tasks. To achieve this, value retention strategies must be planned before design activities take place (e.g., during product planning), where management actors can identify directions for greater value creation. Second, product ecosystems need to consider a broader range of stakeholders involved as partners in value creation and retention during the conceptualization of circular products. To ensure that planned value retention strategies are followed by design teams, strong integration of business processes is required. This should involve the integration of planning and development activities as well as teams responsible for information management across a wider range of functions. Finally, many interdependencies emerge related to the evaluation of environmental and social aspects.

Joustra et al. (2022) describe the use of a design method in the context of circular composites. The purpose of the method is to support product designers in integrating circular economy strategies. The method includes an exploratory life-cycle mapping worksheet and a circular product design framework. Figure 11 presents the consecutive steps of the method and part of the worksheet.

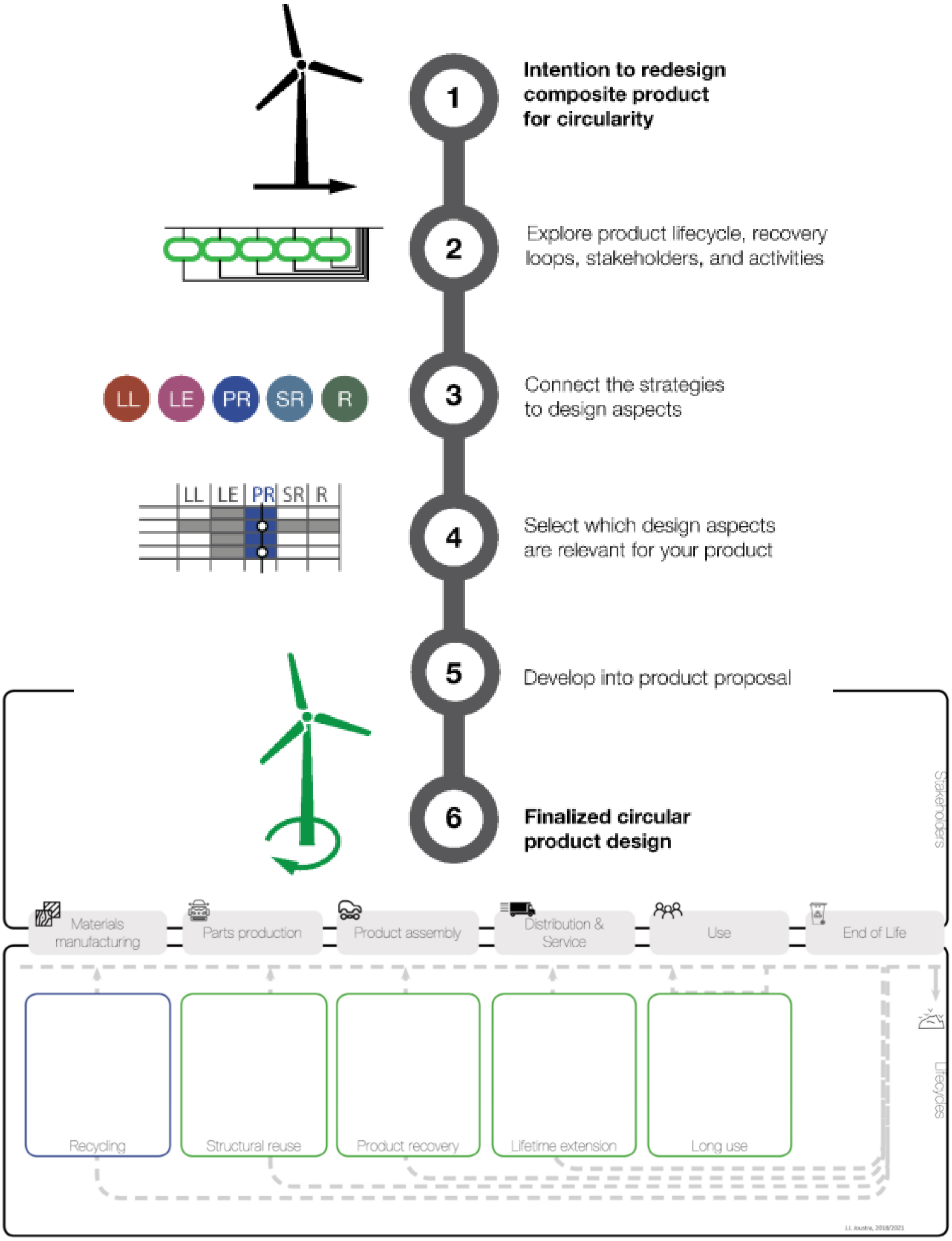

Figure 11: Stages of the PDP Method and Mapping Worksheet
Source: Adapted from Joustra et al. (2022)

The process of the circular product design method follows the numbered steps shown in Figure 11. The process begins with (1) the intention to (re)design a product containing composite materials for a circular economy. Next, (2) the designer uses the life cycle exploration worksheet shown at the bottom of Figure 11 to draw and detail the product life cycle. The mapping starts with a description of the product, followed by the identification of stakeholders for each phase of the product value chain. Then, (3) recovery cycles are explored by describing possible recovery actions to retrieve the product as a whole entity, as components, or as materials at the end of its use phase. The worksheet can be used in group sessions to stimulate discussion and create a shared understanding of the product life cycle and circular opportunities (Joustra et al., 2022).

Recovery cycles are related to circular strategies such as long life, life extension, or material recycling. In the circular composites design method, the designer uses a circular product design framework to connect these strategies to design aspects (4). This framework contains five circular strategies and relates them to 24 design aspects. Three strategies aim to preserve product integrity by ensuring long life, life extension, and product recovery. The two remaining strategies aim to preserve material integrity (maintaining material quality over time) through structural reuse and material recycling. Although product integrity strategies are generally preferred to preserve performance and value, material integrity remains necessary to reprocess products that do not have a next-use cycle. The related design aspects support designers in anticipating recovery through design intentions. The designer can use a subset of design aspects to conceptualize, incorporate, and detail the design proposal (5). Finally, the process results in a circular product design proposal (6) (Joustra et al., 2022).

After analyzing some PDP models, it is necessary to understand the concept of a circular product, which is related to the Circular Economy. This concept is discussed in Section 2.2.2.

2.2.2 Circular Product

Considering resource constraints and environmental pressures, shifting from a linear production model to a circular production model may be a promising path (Hagejärd et al., 2020). In this way, companies would contribute to sustainable development by rethinking the process of developing new products (Bocken et al., 2014).

Subramanian et al. (2019) and Bocken et al. (2016) emphasize that the circular economy needs to be incorporated into the Product Development Process (PDP), since companies must not only meet customer requirements with their products but also consider environmental issues and sustainability throughout the entire life cycle of each product.

When a company adopts the Circular Economy (CE), it may obtain economic, environmental, and social benefits (Ghisellini, Cialani and Ulgiati, 2016; Sauvé, Bernard and Sloan, 2016).

Asif et al. (2021) and Urbinati, Chiaroni and Toletti (2019) highlight that in a circular business model, products must be fully reused or recycled, effectively becoming Circular Products. Circular Products present a value proposition characterized by longer product life cycles, superior services that may also be virtualized, collaborative consumption, and incentives and benefits offered to customers to eventually return used products.

Regarding products, existing research points to Design for X practices and the efficient use of resources. With respect to Design for X practices, the literature highlights Design for Recycling, Design for Remanufacturing and Reuse, Design for Disassembly, and Design for Environment. All of these practices are necessary if companies intend to support the creation of circular products. Furthermore, the Design for Environment practice refers to the use and continuous improvement of virgin raw materials to produce products that are safer for all stakeholders along the value chain, as well as for humans and the environment. In this way, implementing these practices aims to support both biological and technical material cycles (i.e., materials safely return to the environment without contaminating the biosphere) (Urbinati, Chiaroni and Toletti, 2019).

Urbinati, Chiaroni and Toletti (2019) present four principles that circular products must follow:

- **Principle 1 – Energy efficiency and the use of renewable energy sources:** circular products must be designed to use materials characterized by lower emissions and energy consumption, and the production process itself should be designed to improve energy efficiency. The use of renewable energy sources may not be a priority in the early stages of the product life cycle but should be considered as the product and production process become more consolidated.
- **Principle 2 – Optimization of products and processes for resource efficiency:** all circular products and business models focus on the intention to use resources more efficiently and reduce all types of waste as much as possible.

- **Principle 3 – Product design for circularity:** companies must design products and components that can enter a cycle and be completely recycled. A fundamental step is optimizing product and component design in order to reduce recycling costs while maintaining high quality and full product functionality. This principle also implies designing products while considering all possible flows and optimizing the recovery of all product components.
- **Principle 4 – Waste as a resource:** circular products must be designed with the idea of transforming waste into resources. Waste should no longer be considered a problem but rather a source of new value for the same supply chain or for other supply chains.

Boyer, Hunka and Whalen (2021) state that circular products can be understood as products designed to encourage longevity, reuse, and recirculation of resources. This includes extending the lifespan of products and their components through reuse, remanufacturing, and access-based consumption models, as well as closing material loops through recycling.

Boyer, Hunka and Whalen (2021) also note that preferences for circular products vary across countries and cultures, both of which strongly influence the individual perception of product value. There is also research examining how environmental attitudes and knowledge influence preferences for circular products.

Pretner et al. (2021) define circular products as having one of two important characteristics: either they are produced using recycled materials (thus helping to close the production cycle), or they have an extended life cycle because they are more durable or can be resold as second-hand products.

Circular products are designed to optimize resource efficiency. Resource efficiency is optimized by minimizing the environmental impact throughout the product life cycle. This is achieved by revising the traditional product design process, which follows a linear model consisting of production, consumer use, and disposal. Circular products modify these design processes in two ways. The first involves using discarded products as inputs in manufacturing processes to create new products. This closed-loop design model diverts waste that would otherwise end up in landfills. Examples include products made from recycled materials, such as compost and animal feed created from organic waste or clothing made from textile residues or recycled plastic bottles (Batwara et al., 2022; Pretner et al., 2021).

According to Asif et al. (2021) and Pretner et al. (2021), a second type of circular product involves design processes that extend the product life cycle. In this case, products are developed to increase durability or incorporate features that make them easier to reuse, remanufacture, or refurbish. By extending the product life cycle, goods maintain their original purpose but are used for a longer period before eventually being disposed of. Examples include reused or second-hand products. Other examples include remanufactured and refurbished products that are recycled at the end of their life cycle after being upgraded or partially modified before reentering the market.

Evrard et al. (2021) and Pretner et al. (2021) emphasize that, regardless of their form, circular products—like other products with positive environmental attributes—can enhance consumers' perceived value of the product. This occurs because circular products can provide greater intrinsic value by diverting waste from landfills, and these practices align with the personal beliefs and values of some consumers.

However, it is argued that some consumers may associate a negative quality perception with circular products despite their environmental attributes. In such cases, consumers may be willing to pay less for circular products than for new products made from virgin materials. This negative quality perception is related to the fact that recycled inputs originate from post-consumer products (waste) that are introduced into manufacturing processes. Generally, waste requires reprocessing before it can be used in another product. For example, some circular clothing is made from used plastic bottles that are reprocessed to create plastic fibers. Due to this reprocessing, such fibers may be perceived as weaker or contaminated because of their original productive use (Pretner et al., 2021).

The Circular Economy emphasizes the sustainability impact of products and resources in their end-of-life cycles. However, this impact strongly depends on the design and conception phase, that is, the initial stage of production. It is difficult to change resource allocation and infrastructure after the design phase; therefore, it is unlikely that a circular production system will be established unless environmental considerations are incorporated during product design. Consequently, circular product design is a fundamental step for the Circular Economy and for circular supply chain management (Sumter et al., 2021; Wang, Burke and Zhang, 2022).

Wang, Burke and Zhang (2022) highlight that circular product design would allow products to become part of the waste solution. Two elements support circular product design: design for product integrity and design for recycling (both conventional recycling and biological-cycle recycling). Both recyclability and the preservation of product integrity must be incorporated into product design in order to maintain economic and environmental value.

According to Wang, Burke and Zhang (2022), circular product design has evolved to incorporate several concepts:

- Design for inner loops: products are designed to follow the inner loops of the Circular Economy butterfly diagram (see Figure 4). These loops promote design approaches such as reuse, sharing, cascading, remanufacturing, and refurbishment.
- Product life extension and long-life product design strategy: this strategy ensures that products are designed to be durable and long-lasting in order to extend their life cycle. It enables products to be reused multiple times by different users.
- Design for modularity: this design strategy allows products to be easily repaired, remanufactured, and upgraded. It maximizes product usage time through updates and repair processes.
- Ecodesign: this approach systematically integrates environmental aspects into product design, leading to improved design specifications with reduced environmental impact.

After understanding the concept of circular products, another important concept linking the Product Development Process (PDP) and the Circular Economy is the Product-Service System (PSS), or business models, which is discussed in Section 2.2.3.

2.2.3 Business Models – Product-Service Systems

According to Bocken, Schuit, and Kraaijenhagen (2018) and Lüdeke-Freund, Gold, and Bocken (2019), in the Circular Economy (CE) business model innovation plays an important role in fundamentally changing the way business is conducted, going beyond predominant sustainability approaches that focus on efficiency, productivity, and the application of ecological concepts within supply chains. Product-

Service Systems (PSS) are an example of a sustainable business model that has gained popularity within the CE field. Although PSS—where companies remain the owners of products—can enable greater environmental gains, this innovation also involves a higher degree of uncertainty due to its radical departure from traditional business practices.

According to Bocken, Schuit, and Kraaijenhagen (2018), business models provide a framework for describing how business is conducted. They are represented by value proposition (the intended product/service offering—what value is provided and to whom?), value creation and delivery (how the value is provided), and value capture (how the company generates revenue and captures other forms of value). Sustainable business model innovation differs from traditional business model innovation (i.e., models not necessarily focused on sustainability) by explicitly incorporating a triple-bottom-line perspective and considering a broader range of stakeholder interests, including environmental and societal aspects, in addition to delivering superior or unique customer value to create competitive advantage for the company.

Sustainable business models are defined as innovations that create significant positive impacts and/or significantly reduce negative impacts on the environment and/or society through changes in how an organization and its network create value, deliver value, and capture value (i.e., generate or transform economic value) (Bocken, Schuit, and Kraaijenhagen, 2018).

Bocken, Schuit, and Kraaijenhagen (2018), Lüdeke-Freund, Gold, and Bocken (2019), and Guldmann and Huulgaard (2020) also emphasize that a circular business model can be defined as the logic of how an organization creates, delivers, and captures value in order to close and slow material cycles. These circular business model innovations are inherently networked: they require collaboration, communication, and coordination within complex networks of interdependent yet independent actors and stakeholders.

Lüdeke-Freund, Gold, and Bocken (2019) state that the overall objective of business models is to help companies create value by using resources across multiple cycles while reducing waste and consumption. Ideally, waste is completely avoided (i.e., reused), and only renewable energy is utilized. To achieve this, the input side, transformation processes, and output side of business models must be considered. For example, production inputs may consist of used, recycled, or recovered materials and often require the involvement of partners and specialists who understand the benefits and limitations of such materials. The resulting demand for used materials or waste requires appropriate logistics and may lead to the creation of new markets for secondary resources or the expansion of existing ones. In its most advanced form, these resource flows and partnerships lead to symbiotic relationships that enable multiple resource uses, cascading processes, biorefining, continuous recycling, or even the emergence of industrial symbiosis networks based on spatial proximity.

Bocken, Schuit, and Kraaijenhagen (2018), Lüdeke-Freund, Gold, and Bocken (2019), and Guldmann and Huulgaard (2020) emphasize that value is central to both conventional and sustainable business model innovation. The creation of business models begins with defining a value proposition that meets customer needs, suggesting an iterative process in which experimentation is used. A business model framework reflects the logic of strategic thinking about value. This framework consists of the value proposition, the value creation and delivery system, and value capture. By definition, the value proposition is a fundamental statement of a firm’s theory about how to compete, indicating that the company will offer specific products or services to particular customers in a way that provides superior value compared with competitors. Figure 12 presents a sustainable business model that includes the value proposition delivered alongside measurable ecological and social value in combination with economic value.

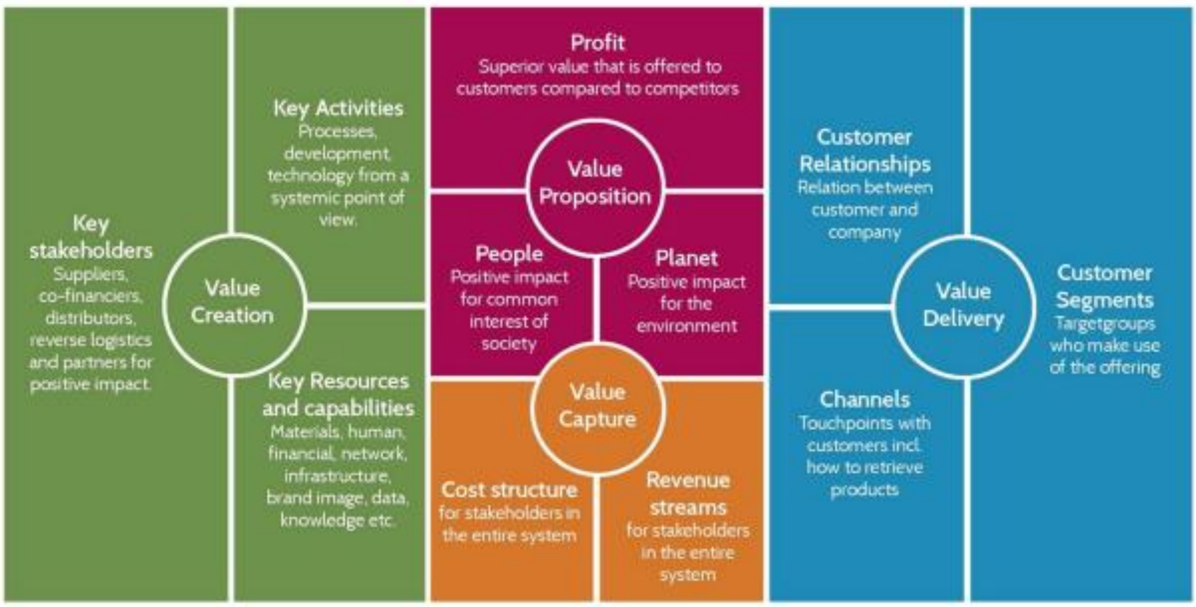

Figure 12: Proposed Sustainable Business Model
Source: Bocken, Schuit and Kraaijenhagen (2018)

Based on the value proposition presented in Figure 12, value creation and delivery describe how to compete, indicating how this theory is put into practice. It begins to shape the organization and architecture of the company and also specifies and describes the sources of the company's competitive advantage, that is, its resources and capabilities. Companies need to collaborate with stakeholders to ensure reverse logistics, for example, which allows them to maximize the value of products and materials. Thus, value creation and delivery in circular business models incorporate multiple stakeholders into the innovation process as collaborative partners (Bocken, Schuit and Kraaijenhagen, 2018).

Finally, value capture concerns the revenue model. In the transition from selling products to selling services—one of the most common examples of a circular business model—the initial investments are often recovered over a longer period compared with direct sales, for example through pay-per-use or performance-based payment systems (Bocken, Schuit and Kraaijenhagen, 2018).

According to Loiseau et al. (2016), a Product-Service System (PSS) can be defined as a mix of tangible products and intangible services designed and combined so that, together, they can meet the needs of the end customer. Products remain the property of companies throughout their entire life cycle, and consumers pay for the use of the product service. In this way, companies have a strong economic incentive to extend the life cycle of their products, ensure they are intensively used, make them as cost- and material-efficient as possible, and reuse components whenever possible.

Loiseau et al. (2016) and Kjaer et al. (2019) present two categories of PSS:

- Use-oriented PSS, in which the product continues to play a central role (e.g., product rental, sharing, or leasing). In this case, there is a potential increase in the product use phase, reducing the need for materials; however, a possible drawback is that it may lead to less careful user behavior, potentially reducing product lifespan.
- Result-oriented PSS, in which there is no predetermined product (e.g., payment per unit of service). In this case, there is greater potential to enhance eco-design and resource efficiency. However, significant changes are required to develop this approach because companies must modify their business models and infrastructure and develop new capabilities (e.g., relationship management skills).

The concept of PSS is closely related to service provision, or the functional economy. The economic objective of the functional economy is to create the greatest possible use value for the longest time while consuming as few material resources and as little energy as possible. Another important aspect is that PSS is no longer based on the product itself but rather on the product's lifespan and functionality, from which services such as sharing and renting emerge, likely reducing resource consumption. Therefore, these concepts contribute to the Circular Economy (Loiseau et al., 2016).

Kjaer et al. (2019) identified five PSS strategies:

- Operational support: the PSS provider supports product operation, for example through performance monitoring or training of customer personnel.
- Product maintenance: the PSS provider maintains the product during use, for example through preventive maintenance, repairs, or upgrades.
- Product sharing: the PSS provider combines retained ownership (e.g., product rental) with shared use among multiple users.
- Return/end-of-life management: the PSS provider is responsible for end-of-life management and determines how products are reused, remanufactured, refurbished, recycled, etc.
- Optimized results: the PSS provider delivers a functional result and dematerializes the offering (e.g., replacing physical transportation with videoconferencing services).

Geissdoerfer et al. (2020) also state that a business model describes the logic of how an organization creates, delivers, and captures value. The same authors propose that business models should be cyclical, extend, intensify, and/or dematerialize material and energy cycles in order to reduce resource inputs and waste and emission outputs within an organizational system. This includes measures such as recycling (being cyclical), extending the use phase (extension), increasing the intensity of the use phase (intensification), and replacing products with services or software-based solutions (dematerialization).

Based on this definition, Geissdoerfer et al. (2020) describe four generic strategies for circular business models: (1) being cyclical; (2) extension; (3) intensification; and (4) dematerialization, which are illustrated in Figure 13.

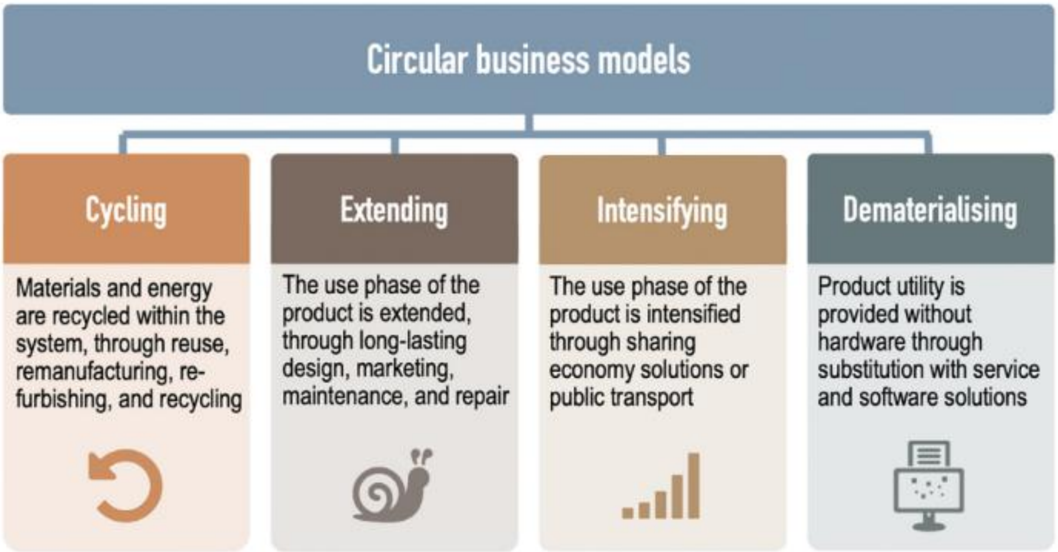

Figure 13: Circular Business Model Strategies
Source: Geissdoerfer et al. (2020)

Being cyclical means that materials and energy are recycled within the system through reuse, remanufacturing, refurbishment, and recycling. For example, decommissioned industrial robots can be reused in small and medium-sized enterprises (SMEs), where their lower acquisition cost enables a viable way to increase productivity through automation (Geissdoerfer et al., 2020).

Extending resource cycles implies extending the product use phase through durable and timeless design, marketing that encourages long usage periods, and practices such as maintenance and repair. For example, Patek Philippe produces luxury mechanical watches designed to last for a long time and with a timeless design that has not changed significantly in recent decades. A marketing campaign reinforces this concept with the slogan: "You never actually own this watch; you merely look after it for the next generation" (Geissdoerfer et al., 2020).

The intensification of resource cycles implies intensifying the product use phase through solutions such as the sharing economy or public transportation. For example, car sharing can significantly reduce vehicle idle time and the mileage traveled per user compared with a conventional ownership-based system (Geissdoerfer et al., 2020).

The dematerialization of resource loops refers to delivering product utility without hardware by replacing it with service and software solutions. For example, offering services or Product-Service Systems (PSS) instead of physical products to fulfill the same function for the user can reduce the number of products produced while improving the customer experience. However, PSS must be intentionally designed to decouple resource consumption; otherwise, it may generate undesired rebound effects that could increase resource consumption (Geissdoerfer et al., 2020).

Fehrer and Wieland (2021) emphasize that within the Circular Economy, business models and business model innovation are discussed as tools to fundamentally change how business is conducted and guide organizations toward sustainable and social innovation. Business models have traditionally been viewed as value creation processes of companies, describing how components of business systems fit together and how sets of decision variables allow firms to use and coordinate their resources to create and deliver value to customers in exchange for appropriate monetary compensation.

According to Fehrer and Wieland (2021), there are four distinct logics for value creation in business models:

- Efficient technical material cycles: value creation in efficient technical material cycles occurs by closing, slowing, and narrowing biological and technical life cycles. Closing cycles refers to maximizing material and energy efficiency through reuse and recycling processes. Slowing cycles involves prolonging the use and reuse of goods over time through the design of long-lasting products, repair, refilling, refurbishment, and upgrading. Narrowing cycles means reducing resource use associated with production processes, resulting in efficiency improvements. Therefore, technical material cycles support the use of fully renewable, recyclable, or biodegradable resources (Fehrer and Wieland, 2021).
- Effective product-service cycles: value creation in product-service cycles occurs by replacing product ownership with access to products and services, for example through rental, leasing, or pay-per-use models. These cycles are commonly discussed under the concept of Product-Service Systems (PSS). The underlying goal of PSS is to rethink how material and service needs are satisfied and to work toward alternative goods and services that are more environmentally benign and more efficient in terms of materials and energy (Fehrer and Wieland, 2021).
- Socio-collaborative cycles: these cycles emphasize collaboration rather than competition as a central practice for the transition to an effective Circular Economy. Value creation focuses on linking actors to execute

sustainable practices effectively. This approach aligns with the concept of using idle assets in the sharing economy, which reduces demand for new manufacturing. In this way, consumption cycles are slowed and underutilized resources are activated. Socio-collaborative cycles keep assets within the economy and create new opportunities for ecosystem stakeholders. Customers, for example, participate in alternative consumption systems based on sharing, which utilize the idle capacity of already produced goods and available time resources (Fehrer and Wieland, 2021).

- Symbiotic ecosystems: symbiotic ecosystems create value by closing resource cycles (similar to recycling). However, unlike the previously described business model logics, symbiotic ecosystems rely on collective action and collaboration among multiple actors in their value creation logic. Sustainability challenges are so extensive that a real transition toward sustainable development requires joint efforts and collective entrepreneurship. The sustainability efforts of a single company alone are unlikely to achieve success. Symbiotic ecosystems consider broader institutional structures and the integration of horizontal networks and recognize that the success of sustainable innovations largely depends on the structure and dynamics of their surrounding environment (Fehrer and Wieland, 2021).

Table 7 presents the four value creation logics in business models mentioned by Fehrer and Wieland (2021).

Value Creation Logic	Efficient Technical Material Cycles	Effective Product-Service Cycles	Socio-Collaborative Cycles	Symbiotic Ecosystems
Content: Changing and creating (new) activities	Maximizing material and energy efficiency: Developing and designing for durability; Repairing, refilling, and refurbishing; Recycling and collection; Upgrading.	Offering functionality instead of ownership: Pay-per-use; Leasing; Renting; Maintenance; Service creation.	Proactively engaging all stakeholders: Sharing; Diffusion of sustainable practices; Slowing consumption.	Driving systemic change: Redefining the role of companies in society and the environment; Restoring and regenerating; Scaling solutions.
Structure: Linking activities, resources, and actors in new ways	Circular supply chains, vertical integration (forward and backward)	Service solutions, vertical integration (forward)	Collaborative consumption platforms, network integration	Open associative and collaborative networks, network integration
Governance: Ways of governing/managing the system of activities	Supply chain management, firm-centered contractual models	Service management, firm-centered with contractual models	Platform orchestration, decentralized with collective contractual models	Collective entrepreneurship, multi-organizational governance, decentralized with collective ownership

Table 9: Value Creation Logics in Business Models
Source: Adapted from Fehrer and Wieland (2021)

Corroborating the definitions of business models presented, Awan and Sroufe (2022) state that a business model describes the architecture of how a company creates and delivers value to customers and the mechanisms used to capture a portion of that value. In this sense, business models aim to create, deliver, and capture value while implementing circular strategies that can extend the life cycle of products and components (e.g., repair and remanufacturing) and close material loops (e.g., recycling). Therefore, a business model can be understood as one in which the conceptual logic for value creation is based on utilizing the economic value retained in products after their initial use and through reuse-oriented offerings.

3. Proposed Product Development Model with a Circular Economy Approach

In this chapter, the proposed model for product development that incorporates the concepts of the Circular Economy (CE), along with its respective stages, is presented.

3.1 PDP Model for Packaging

Section 2.2.1 presented several Product Development Process (PDP) models and their characteristics. After analyzing all the models presented, it was decided to select a base model to develop a product development model that incorporates Circular Economy (CE) concepts. The model chosen as the basis was the Stage-Gate model proposed by Robert Cooper.

The Stage-Gate model was selected because it presents several stages that facilitate the incorporation of concepts and tools related to CE, and also because it is the most widely used new product development framework in the literature (Awais & Tipu, 2012). In addition, Kitsios and Kamariotou (2021) state that the Stage-Gate model is the most widely evaluated, referenced, and implemented innovation management model in the world, used by companies of all sizes and adopted across many sectors.

Figure 14 presents the proposed PDP model, which incorporates CE concepts.

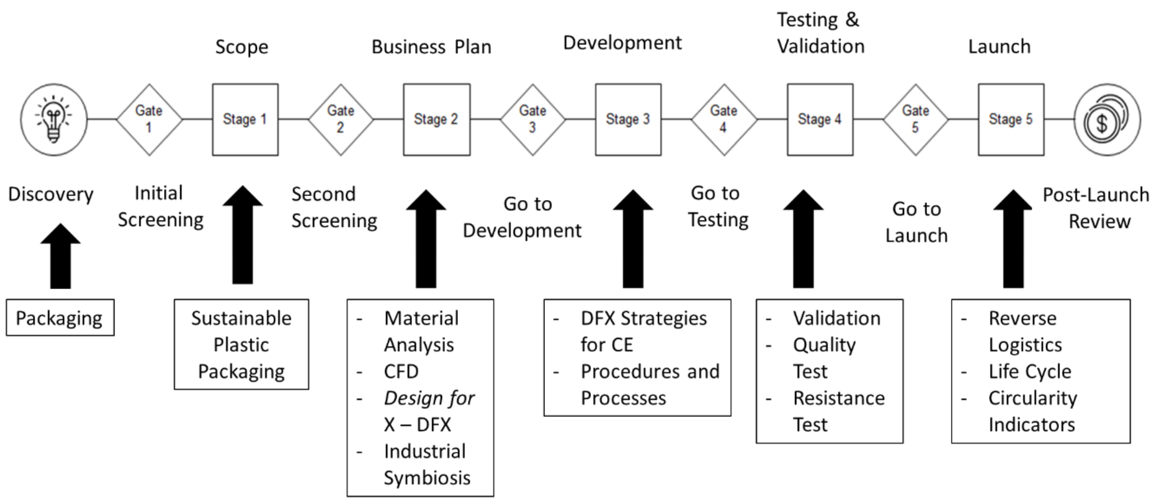

Figure 14: Proposed PDP Model for Packaging
Source: Prepared by the author

The proposed model is based on the Stage-Gate model proposed by Cooper (1990), in which all stages were adapted for the development of packaging designed according to Circular Economy (CE) concepts.

Within each stage, activities were proposed that the organization should evaluate and follow in order to implement CE. Therefore, each activity must be analyzed in detail to effectively put CE concepts into practice, ensuring that the products can be considered circular and that components and materials can be used and reused for longer periods.

In the following sections, each stage will be explained in detail.

3.2 Discovery: Packaging

According to Sastre et al. (2020), packaging consists of containers or wrappings whose main function is to contain, protect, and transport goods. Packaging can be classified as complex and systemic, as it involves predictable and/or unexpected interactions among its components and processes. Therefore, it is essential to consider packaging from the perspective of its entire life cycle.

Packaging originated from the human need to preserve food, evolving from the use of leaves and natural materials to leather, glass, and metal during the Middle Ages, when natural resources were believed to be infinite. The creation of supermarkets transformed commerce, increasing the need for prolonged product preservation and intensifying competition among packaging solutions. With technological advances, plastic molding and creativity in packaging design flourished. Currently, the packaging market is global, with Brazil emerging as a reference in new technologies, such as green plastic and easy-open caps. The role of packaging has also evolved to include important marketing aspects (Nascimento, 2023).

According to Guiné et al. (2020) and Firouz, Mohi-Alden, and Omid (2021), packaging plays a crucial role in product development and impacts several areas, ranging from product protection to brand promotion. Some characteristics of packaging include:

- Packaging has the primary function of protecting the product against damage during transportation, storage, and handling. This is especially critical for fragile, perishable, or environmentally sensitive products.

- Packaging provides essential information to consumers, such as instructions for use, ingredients, nutritional information, expiration dates, and other regulatory information.
- Packaging is an extension of brand identity. Colors, design, and messages on the packaging help build and communicate the brand image, establishing an emotional connection with consumers.

In the introduction of this thesis, specifically in Section 1.1, which presented the research characterization, the importance of packaging for the global market and some problems caused by the increase in packaging consumption were highlighted. Souza (2021) states that packaging quickly changes its status from functional to non-functional because some packages cease to be useful once the product is removed or consumed. Consequently, packaging becomes waste and is not always disposed of properly.

The issue of plastic packaging was also highlighted, as it takes a long time to decompose in nature and not all plastics are recycled.

With the continuous environmental degradation caused by the increase in packaging waste, there is a growing demand for more robust approaches that require the design, production, consumption, and recycling of packaging in a more sustainable way (Zhu et al., 2022).

Sastre, de Paula, and Echeveste (2022) emphasize that the excessive amount of packaging on the planet challenges sustainable development, and the circular economy suggests that the waste problem should be addressed from the design stage. This model is based on concepts of economic, natural, and social capital, as well as on the transition to renewable energy sources. Therefore, developers, manufacturers, and packaging professionals have the responsibility to meet current demands. Although packaging may appear structurally simple, it is complex in terms of its life cycle, since the choice of materials and formats affects its function, production, distribution, use, and disposal, as well as causing environmental impacts. The search for biodegradable packaging reflects the need to reduce these impacts. Packaging involves multiple fields such as design, communication, engineering, and chemistry, revealing its systemic complexity.

In this context, it is extremely important that packaging have a PDP focused on the Circular Economy. Therefore, it is necessary to develop a PDP model for the development of sustainable packaging.

3.3 Stage 1: Scoping – Sustainable Plastic Packaging

Sustainable packaging can be defined as packaging designed with recyclable materials that meet market criteria for their functional and social purposes while considering economic feasibility and minimizing environmental impact through life cycle assessment (Sastre, 2022).

According to Kautish, Paço, and Thaichon (2022), plastic packaging is widely used across several sectors due to its versatile properties, light weight, durability, and relatively low cost. Some important aspects of plastic packaging include:

- **Versatility:** Plastics offer a wide range of design options, shapes, and sizes, making them suitable for packaging various products, from food and beverages to electronic and pharmaceutical products.
- **Light weight and durability:** Plastic packaging is lightweight, which facilitates transportation and reduces logistics costs. In addition, it is durable and provides good protection against physical impacts, humidity, and other environmental factors.
- **Protective barriers:** Plastic can be formulated to create effective barriers against oxygen, light, moisture, and odors, helping preserve the quality and shelf life of packaged products.
- **Cost-effectiveness:** Compared to some packaging materials, plastic is often more economical to produce, which may contribute to reducing packaging costs.

Rai et al. (2021), Testa et al. (2021), and Holler et al. (2023) emphasize that sustainable plastic packaging is a response to the environmental challenges associated with the extensive use of conventional materials. These types of packaging aim to minimize negative environmental impacts, from production to disposal, and generally incorporate more environmentally friendly practices throughout their manufacturing process and life cycle. Some aspects related to sustainable packaging include:

- **Biodegradable and compostable materials:** A sustainable approach involves the use of biodegradable or compostable plastics. These materials degrade more quickly in the environment, reducing long-term impacts.
- **Plastics from renewable sources:** Plastic materials derived from renewable sources, such as sugarcane or corn starch, are considered more sustainable than those derived from non-renewable sources, such as petroleum.
- **Recycling:** Some sustainable packaging solutions are designed to be more easily recyclable. This may involve the use of mono-materials or specific polymers that are more compatible with existing recycling systems.
- **Recycled materials:** The use of recycled plastics in packaging manufacturing is a common practice to reduce dependence on virgin raw materials. Recycling contributes to waste reduction and resource conservation.
- **Efficient design and waste reduction:** The design of sustainable packaging often prioritizes material efficiency, minimizing unnecessary plastic use and reducing the amount of waste generated.
- **Material innovations:** Ongoing research focuses on the development of new materials that are environmentally friendly. This includes plastics that can dissolve in water, bio-based plastics, and materials that can be easily recycled.
- **Consumer awareness:** Many companies emphasize the sustainable nature of their packaging to attract environmentally conscious consumers. Informing consumers about the importance of recycling and proper disposal is a key part of this strategy.
- **Industry collaboration:** Collaboration among different sectors of the industry, including packaging manufacturers, retailers, and recycling companies, is essential to create more sustainable solutions and align efforts toward more responsible practices.

With the aim of implementing Circular Economy (CE) principles within the Product Development Process (PDP), plastic packaging represents an opportunity for many companies and is the focus of this thesis.

3.4 Stage 2: Business Plan

For an organization to decide to incorporate Circular Economy (CE) principles into the Product Development Process (PDP), it is important to consider a series of factors and practices, since CE aims to maximize the value of resources, minimize waste, and reduce environmental impacts throughout the product life cycle. Based on Lin (2018), Ko (2020), Diaz, Reyes and Baumgartner (2022), and Joustra et al. (2022), some considerations that must be taken into account include:

- **Sustainable Design:** product design should be oriented toward sustainability from the outset. This includes selecting sustainable materials and applying principles such as design for disassembly, durability, and reparability.
- **Sustainable Materials:** selecting materials that are renewable, recyclable, or biodegradable. It is important to seek sustainable sources of materials and establish responsible supply chains.
- **Product Life Cycle:** conducting a detailed life cycle analysis of the product to identify opportunities to reduce environmental impacts at all stages, from production to disposal.
- **Reverse Logistics:** planning effective reverse logistics systems that allow the collection and recovery of used products for reuse, recycling, or remanufacturing.
- **Circular Business Models:** considering business models that encourage reuse, sharing, leasing, remanufacturing, and the recovery of products after use.
- **Innovation and Technology:** remaining open to technological innovations that may improve product sustainability, such as new materials, manufacturing processes, and recycling methods.
- **Education and Awareness:** educating employees, customers, and partners about the principles of the circular economy and promoting awareness regarding the importance of recycling and proper disposal.
- **Regulations and Certifications:** keeping up to date with environmental regulations and seeking certifications that attest to product sustainability, such as eco-labels.

- **Partnerships and Collaborations:** collaborating with suppliers, recyclers, and other stakeholders to optimize material and resource flows.
- **Impact Assessment:** conducting regular assessments of environmental and social impacts throughout the product life cycle to measure progress toward a circular economy.
- **Service Economy:** considering the possibility of offering services instead of only physical products, such as product leasing, maintenance, and upgrades.
- **Waste Minimization:** reducing waste during the manufacturing process and promoting recycling of waste whenever possible.
- **Information Technology:** using information technology to track and manage the product life cycle and optimize reverse logistics.
- **Sustainable Corporate Culture:** developing a corporate culture that values sustainability and environmental responsibility.

In Stage 2 of Cooper's Stage-Gate model, referred to as the business plan stage for packaging production, the focus is on developing a comprehensive plan that addresses key aspects of the venture. During this stage, it is essential to conduct an in-depth market analysis to understand consumer demands, identify competitors, and recognize trends within the packaging sector. At the same time, a solid business plan must be developed, including the identification of target market segments, a preliminary financial analysis to assess economic feasibility, and strategies to mitigate business risks. Stage 2 also requires the development of a strategic marketing plan, including product positioning, pricing strategies, and operational strategies, such as establishing an efficient supply chain and evaluating production capacity (Cooper, 2008).

Stage 2 of the Stage-Gate model is extremely important for the development of the entire model because the success of the product depends on the economic feasibility of the business plan. Therefore, companies must carefully analyze this stage to avoid designing a product that is economically unfeasible.

In the proposed model (Figure 14), the planning stage includes at least four activities: Material Analysis; CFD; CE Strategies; and Industrial Symbiosis.

3.4.1 Material Analysis

Material analysis plays a crucial role in the development of sustainable packaging, aiming to minimize environmental impacts throughout the product life cycle. For sustainable packaging, it is essential to consider several aspects in the material selection process. First, preference is given to recyclable, biodegradable, or compostable materials in order to reduce waste and promote more environmentally responsible practices (Testa et al., 2021).

Life Cycle Assessment (LCA) of materials is a key component in this process, examining stages from raw material extraction to final disposal. Materials that require less energy during production, transportation, and recycling are generally preferred. In addition, the sustainable origin of materials is crucial, encouraging the selection of renewable sources and reducing the use of non-renewable resources (Jugend et al., 2020).

The incorporation of innovative technologies, such as biodegradable plastics based on organic materials, is also considered. However, it is important to ensure that these materials actually provide significant environmental benefits and that their degradation does not result in harmful by-products for the environment (Ko, 2020).

Kautish, Paço and Thaichon (2022) emphasize that reducing the weight and volume of packaging, without compromising its effectiveness, is another relevant strategy to minimize material use. Furthermore, design for recycling is fundamental, facilitating the separation of different materials during the recycling process.

In summary, material analysis for sustainable packaging involves a holistic approach that considers not only functionality and performance, but also environmental impacts throughout the entire product life cycle. Therefore, material analysis is essential for the development of sustainable packaging, since the type of material directly influences the sustainability of the product.

3.4.2 CFD (*Circular Function Deployment*)

According to Vimal et al. (2022), the Quality Function Deployment (QFD) method has been widely used to translate customer requirements into engineering specifications in product development and production. In this context, the Circular Function Deployment (CFD) method integrates circularity concepts with QFD as a tool to implement Circular Economy (CE) principles during the design phase. CFD can replace traditional customer requirements with circularity requirements so that a product can be developed according to circular principles.

The incorporation of circularity concepts into QFD can be a valuable approach for promoting sustainable practices in the development of products and services. In this way, organizations can not only meet customer needs but also adopt more environmentally responsible practices. This approach aligns with a more holistic perspective of product development, considering not only quality and customer satisfaction but also social and environmental impacts (Siwiec, Pacana, & Gazda, 2023).

With the objective of developing a CFD for packaging, several circularity characteristics for packaging were considered. These include:

- **Design for Recyclability:** packaging design is conceived to facilitate the recycling process. This may include the selection of recyclable materials and the development of packaging that can be easily separated for recycling.
- **Use of Recycled Plastics (PCR – Post-Consumer Recycled):** incorporation of recycled plastics into the packaging manufacturing process, promoting closed-loop systems and reducing the demand for virgin raw materials.
- **Reduced Plastic Design:** strategies to minimize the amount of plastic used in packaging, reducing waste and the environmental impact associated with production.
- **Reusable Packaging:** exploration of reusable packaging models, encouraging consumers to return packaging so that it can be cleaned and reused.
- **Innovation in Biodegradable Materials:** investment in biodegradable or compostable plastic materials that naturally degrade over time, minimizing the persistence of plastic waste in the environment.
- **Circular Business Models:** adoption of circular business models, such as refill programs, in which consumers can refill their original packaging, reducing the need for new packaging.
- **Traceability and Transparency in the Supply Chain:** implementation of systems that track the origin and composition of packaging materials, ensuring transparency and enabling sustainable decision-making throughout the supply chain.

Some characteristics of the packaging production process were also considered in the development of the CFD, such as:

- **Material – Appropriate Type of Plastic:** selecting the appropriate plastic type for the specific application is essential. Different plastics have distinct properties, such as chemical resistance, durability, flexibility, and transparency. Choosing the correct material directly affects packaging functionality.
- **Barrier and Protection:** packaging must provide adequate protection for the product against external factors such as light, moisture, oxygen, and microorganisms. This is especially critical for food, pharmaceuticals, and other sensitive products.
- **Ergonomic Design and Functionality:** packaging design should be practical and meet consumer needs. This includes ease of opening, closing, and handling. Ergonomic packaging can improve the user experience.
- **Legislation and Regulation:** compliance with local and international regulations and standards is essential. This includes food safety requirements, mandatory labeling information, material restrictions, and other industry standards.
- **Efficiency in Transportation and Storage:** the size, shape, and strength of packaging directly influence logistical efficiency. Optimized packaging can reduce transportation and storage costs and minimize wasted space.
- **Aesthetic Appeal and Marketing:** packaging often plays a crucial role in purchasing decisions. Attractive design, informative labels, and innovative packaging can differentiate a product in the market and influence consumer choice.

Figure 15 presents an example of part of the QFD House of Quality adapted with circularity concepts to support the development of the CFD for the packaging sector.

	Material	Barrier and protection	Ergonomic design	Functionality	Legislation and regulation	Transportation	Storage	Marketing
Design for recyclability								
Use of recycled plastics								
Reduced design								
Reusable packaging								
Innovation in biodegradable materials								
Circular business models								
Traceability								

Figure 15: Example of a CFD for the packaging sector
Source: Prepared by the author

3.4.3 Design for X activity (CE strategy)

Circular economy strategies play a fundamental role in the product development process, aiming to create products that are more sustainable, efficient, and environmentally responsible. Design for X (DFX) strategies are good approaches for implementing the circular economy.

The DFX strategies presented by Lin (2018) are relevant to consider: design for manufacturing, design for assembly, design for disassembly, design for users, design for quality, design for supply chain management, design for life cycle, and design for the environment.

When adopting these strategies, procedures and processes need to be modified in order to meet these requirements.

The circular economy involves the integration of green technology, green materials, and green manufacturing into the design process of environmentally friendly products. This means prioritizing green energy technologies, biodegradable materials, and minimizing manufacturing processes that are harmful to the environment, known as the three green DNAs (Ko, 2020).

According to Diaz, Reyes and Baumgartner (2022) and Joustra et al. (2022), product designers can use tools to integrate circular economy strategies into their design processes. These include mapping the product life cycle, identifying stakeholders, exploring recovery cycles, and using a circular product design framework that relates circular strategies to design aspects.

In this context, the following DFX strategies for the circular economy can be considered:

- Design for durability: designing high-quality and durable products so that they last longer and require fewer replacements.
- Design for disassembly: designing products so that they can be easily disassembled, allowing the recovery of components and materials for reuse.
- Material recycling: collecting and recycling materials from used products to reintegrate them into the supply chain, minimizing the extraction of new raw materials.
- Remanufacturing: disassembling used products, replacing or refurbishing components, and reassembling them to be resold as products with quality similar to new ones.
- Product leasing and sharing: offering products as services, allowing customers to rent or share products instead of purchasing them.
- Service business models: shifting the focus from selling products to selling services related to the products, such as maintenance, updates, and support.
- Modular design: designing products in modules that can be easily replaced or upgraded, extending the product life cycle.
- Technology: using advanced technologies, such as the Internet of Things (IoT), to track product performance and optimize resource use.

After defining the DFX strategies for the circular economy that each product will adopt, procedures and processes need to be developed or modified so that these strategies can be incorporated into the product. Figure 16 presents a generic example of how products can be related to circular economy strategies.

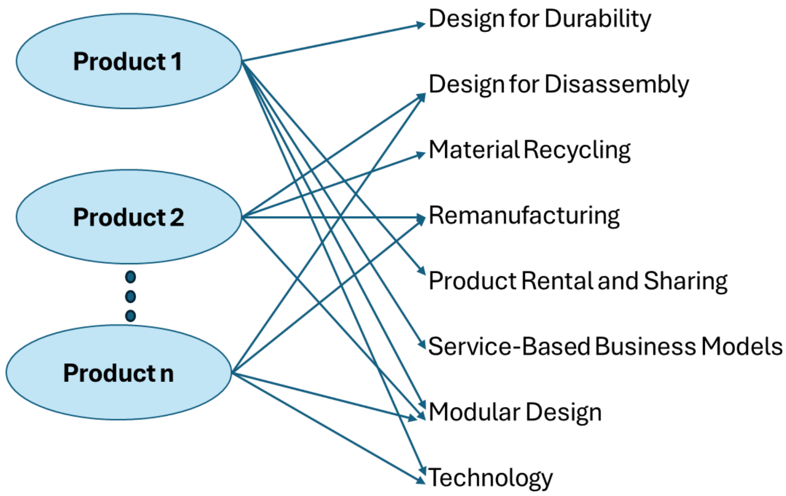

Figure 16: Relationship between products and CE strategies
Source: Prepared by the author

3.4.4 Industrial symbiosis activity

According to Moreno et al. (2016), Vihma and Moora (2020), Khan and Haleem (2021), Sumter et al. (2021), and Wang, Burke and Zhang (2022), industrial symbiosis is a concept based on cooperation and the exchange of resources, by-products, and waste between companies in order to create a more sustainable and efficient system. This concept is inspired by nature, where several species interact symbiotically, benefiting from one another. In the industrial context, symbiosis aims to minimize waste, optimize resource use, and reduce environmental impact. Some important characteristics of industrial symbiosis include:

- Resource exchange: companies involved in industrial symbiosis collaborate to identify opportunities to share resources such as raw materials, water, energy, heat, space, knowledge, and labor.
- Waste reuse: instead of discarding waste, companies seek ways to reuse it in other processes, transforming what was previously considered a by-product into a valuable resource.
- Energy and environmental efficiency: industrial symbiosis aims to improve energy efficiency and resource management, resulting in a significant reduction in environmental impacts.
- Cost reduction: collaboration between companies can lead to significant cost reductions, as resources are shared and waste is minimized.

- Regional benefits: industrial symbiosis often focuses on clusters or industrial parks where several companies are located close to each other, facilitating collaboration.
- Innovation and sustainability: the industrial symbiosis approach encourages innovation and the adoption of more sustainable practices, which can improve the company's image and competitiveness.

Industrial symbiosis promotes a more holistic and sustainable approach to industrial operations, helping to reduce environmental impact, improve efficiency, and create collaborative relationships among companies. This approach is increasingly relevant in a world concerned with sustainability and responsible resource management, in order to apply several concepts of the circular economy.

In this context, top management must decide whether to implement industrial symbiosis and seek other companies that can collaborate so that circular economy concepts can be put into practice.

3.5 Stage 3: Development

In Stage 3 of Cooper's Stage-Gate model, dedicated to the development of sustainable packaging, the emphasis is placed on transforming concepts into tangible reality. During this phase, the focus is on the materialization and improvement of the prototypes conceived in the previous stages, incorporating crucial elements of sustainability. The production of packaging prototypes using sustainable materials identified in the Business Case stage is essential. At the same time, production processes are optimized in order to improve efficiency and reduce environmental impacts (Cooper, 2008).

The product development stage that incorporates circular economy concepts must be carried out by a multifunctional team with different areas of expertise, since the characteristics proposed by the circular economy need to be present for the product to be considered circular. It is at this stage that circular economy concepts are applied and put into practice, as the product must be produced considering the 3Rs approach (Reduction, Reuse, and Recycling) (Lin, 2018; Diaz, Reyes and Baumgartner, 2022).

Therefore, it is at this stage that circular economy concepts are implemented according to what was planned. Designers must analyze the product portfolio defined during the planning stage and the circular economy concepts that the organization is capable of implementing so that the products can become circular.

In this sense, the development stage of the proposed model was summarized into two activities: circular economy strategies and procedures and processes.

3.5.1 DFX strategies for CE and procedures and processes

The DFX strategies for CE were presented in section 3.4.3 of this thesis. After defining which CE strategies each product will incorporate, it is necessary to define the procedure for each of them. In this sense, Figure 17 presents a form to assist the team in developing procedures and processes for each product based on the product's CE strategies.

Product name:			
Product description			
	Circular Economy Strategy		
	Design for Durability		Product Rental and Sharing
	Design for Disassembly		Service-Based Business Models
	Material Recycling		Modular Design
	Remanufacturing		Technology
Description of Circular Economy Strategies			

Figure 17: Product form with incorporated CE strategies
Source: Prepared by the author

In order for the organization to develop procedures and define processes for each CE strategy adopted in this model, some questions can be formulated to provide support.

For design for durability:

- How long will the product be designed to last? Consider a long lifespan.
- Which materials are important for the product to last for the defined period?
- Which technology should be used so that customers remain satisfied over a long period?

For design for disassembly:

- How long does it take to disassemble the product?
- Which materials are important and can be reused?
- It may be useful to map the disassembly time and identify the important materials.

For material recycling:

- What are the criteria for selecting recycled material;
- What tests must these materials pass to be considered suitable for use?
- Where can these materials be collected? Which suppliers?

For remanufacturing:

- Can the product be rebuilt or updated?
- Is it possible to upgrade the product?
- Is it worthwhile to have a line of remanufactured products?

For product leasing and sharing:

- Which materials can be used so that the product can be used by several different customers?
- Does the product need to be more robust?
- Will leasing or sharing be the responsibility of a division of the company or of a partner company? If it is the responsibility of a partner company, does it have the capability to carry out minor repairs if necessary?

For service business models:

- How will the maintenance process be carried out? Can the customer perform it or only technical support?
- Who will update the product?
- Is there a need to provide training for the customer? Who will provide this training?

For modular design:

- How can the product be divided into modules?

- Will the modules be manufactured separately?
- Can a module be updated separately?

Technology: use advanced technologies, such as the Internet of Things (IoT), to track product performance and optimize resource use.

- Which technologies will be used?
- Will a database be used to collect information about products and customers? Who will collect this information, and how will it be collected?

In addition to these questions, organizations may add or remove some of them depending on their product and the characteristics of the company.

3.6 Stage 4: Testing and validation

In Stage 4 of Cooper's Stage-Gate model, which focuses on testing and validation for sustainable packaging, the developed products undergo a crucial phase of practical evaluation. During this stage, sustainable packaging is subjected to comprehensive testing to verify its compliance with expectations related to performance, resistance, and durability. In addition, environmental aspects are carefully examined to confirm that the packaging aligns with the established sustainability goals. This stage ensures that the packaging meets quality, performance, and sustainability standards before moving forward to full implementation (Cooper, 2008).

In this sense, the testing and validation stage of the proposed model is summarized into three activities: quality testing, resistance testing, and validation.

Quality testing plays a fundamental role in the development and validation of sustainable packaging. The optimization of production processes aims to ensure that sustainable materials are efficiently incorporated while maintaining high quality standards. A holistic approach to quality testing, integrating technical and practical aspects, is essential to ensure that sustainable packaging not only achieves high performance standards but also meets consumer expectations and stands out in the market (Testa et al., 2021).

Lv et al. (2022) and Holler et al. (2023) emphasize that resistance testing is a critical component in the evaluation of sustainable packaging. During the development stage, sustainable prototypes undergo meticulous tests to evaluate their resistance in order to ensure that they meet essential durability standards. These tests include analyzing the packaging's ability to withstand loads, resist external pressures, and maintain structural integrity during handling and transportation. The optimization of production processes, carried out simultaneously, aims to ensure that the incorporated sustainable materials maintain adequate levels of resistance. In the testing and validation stage, detailed resistance assessments are conducted to verify the practical performance of the packaging under real-world conditions.

According to Kautish, Paço and Thaichon (2022), the validation of sustainable packaging is a crucial process. During the development stage, prototypes are carefully designed based on sustainable concepts and subjected to practical tests to ensure resistance, durability, and functionality. At the same time, production processes are optimized to ensure efficiency in implementing new materials and sustainable practices. Sustainable products undergo comprehensive evaluations, including environmental tests to confirm their compliance with sustainability standards. Validation not only certifies the environmental integrity of sustainable packaging but also ensures its effectiveness in real-world conditions, consolidating its readiness for full implementation in the launch stage. This integrated validation process plays an essential role in ensuring that packaging not only meets sustainability criteria but also stands out in a competitive market, aligning with consumer expectations and practical demands (Kautish, Paço and Thaichon, 2022).

3.7 Launch

The Launch stage addresses activities related to product management and monitoring after development, focusing on aspects such as maintenance, evolution, customer support, and performance evaluation.

In Stage 5 of Cooper's Stage-Gate model, entitled launch, the sustainable packaging that has passed through the previous stages is officially introduced into the market. This stage represents the full implementation of the product after the successful completion of the development, testing, and validation phases. During the launch, marketing strategies are activated to communicate the sustainable attributes of the packaging to consumers and promote market acceptance. Sales teams are mobilized to establish partnerships with customers and distributors, ensuring effective market penetration. Continuous monitoring of product performance in the market environment is crucial, allowing rapid and ongoing adjustments based on customer feedback and constantly changing market conditions. The successful completion of this stage confirms not only the sustainability of the packaging but also its acceptance and relevance in the market, contributing to the long-term success of the product (Cooper, 2008).

In this sense, the launch stage of the proposed model includes three activities that are important for the efficient implementation of the circular economy in the product development process. These activities are reverse logistics, life cycle, and circularity indicators.

3.7.1 Reverse logistics

According to Jugend et al. (2020), Sumter et al. (2020), Vihma and Moora (2020), Khan and Haleem (2021), and Wang, Burke and Zhang (2022), reverse logistics is the process that involves the collection, transportation, sorting, and management of products, materials, or waste after their use by the consumer, aiming at recovery, reuse, recycling, or proper disposal, in accordance with environmental principles and regulations. It includes the return of discarded products to the production cycle, promoting waste reduction, resource preservation, minimization of environmental impacts, and compliance with legal obligations, playing an essential role in the circular economy and in sustainable waste management.

According to Jugend et al. (2020), Sumter et al. (2020), Vihma and Moora (2020), Khan and Haleem (2021), and Wang, Burke and Zhang (2022), in order to implement reverse logistics effectively, a company should begin by evaluating feasibility and defining clear objectives. Next, it is necessary to identify the products or materials that will be targeted by this process in order to establish partnerships with suppliers and reverse logistics service providers. Another important point is to develop solid processes and systems, focusing on the collection, sorting, and transportation of returned products or materials. It is necessary to educate customers and employees, comply with regulations, evaluate performance through key indicators, and pursue continuous improvements. Transparency in communicating results is essential. Reverse logistics not only contributes to sustainability but can also generate financial benefits and improve the company’s reputation.

3.7.2 Life cycle

Jugend et al. (2020), Leal et al. (2020), Fernando et al. (2021), He et al. (2021), Pérez-Ortega et al. (2021), and Vimal et al. (2022) emphasize that the product life cycle is a representation of the stages through which a product passes from its conception, production, market launch, consumer use, and eventually its withdrawal from the market. This concept is often divided into several distinct phases: introduction, growth, maturity, and decline. Each phase has specific characteristics in terms of sales, profitability, competition, and consumer demand. The product life cycle is important for product management strategies, marketing, and sustainability, as it helps companies understand when and how to adjust their strategies over time to maximize product success.

According to Jugend et al. (2020), Leal et al. (2020), Fernando et al. (2021), He et al. (2021), Pérez-Ortega et al. (2021), and Vimal et al. (2022), the product life cycle in the circular economy promotes the idea that a product does not become waste but rather a valuable resource that can be used repeatedly. This not only helps conserve natural resources, reduce pollution, and lower production costs, but also aligns with sustainable principles that are increasingly valued.

By controlling the life cycle of its products, a company can use reverse logistics so that the product returns to the company for recycling, remanufacturing, and reuse of materials and components in order to apply the circular economy strategies adopted by the company.

3.7.3 Circularity indicators

Section 2.1.3 discussed several strategies and metrics to measure the circular economy (CE) and evaluate its impact on organizations. Linder, Sarasini and Van Loon (2017) propose circularity metrics based on economic value, measuring the fraction of a product that originates from used products. Pauliuk (2018) suggests quantitative indicators based on material flow analysis, material flow cost accounting, and life cycle assessment. Figge et al. (2018) emphasize monitoring resource flows along supply chains to maximize the use of recovered materials and minimize the use of virgin resources. Resource longevity is also highlighted as an indicator, measuring the time a resource is used for the first time due to product refurbishment and recycling (Franklin-Johnson, Figge, Canning, 2016; Figge et al., 2018). In addition, Niero and Kalbar (2019) apply a multi-criteria decision analysis to measure circularity, using indicators based on material circularity and life cycle indicators relevant to a case study of beer packaging in the United Kingdom and India. These metrics and strategies provide comprehensive approaches to evaluating the circular economy in organizations and products.

In this sense, circularity indicators are metrics used to assess the performance of processes, products, or systems in relation to circular economy principles. They provide a way to measure and communicate progress toward more sustainable and circular practices. Some indicators that a company can adopt to evaluate circularity are:

- Recycling rate: this indicator measures the amount of materials or products that are recycled in relation to the total waste generated. A higher recycling rate indicates greater circularity.
- Product lifespan: evaluates the average length of time that a product remains functional before being discarded. Products with a longer lifespan are considered more circular.
- Material recyclability: indicates how easily the materials in a product can be recycled. Easily recyclable materials increase the circularity of the product.
- Recycled content: this indicator measures the amount of recycled material incorporated into new products. Higher recycled content demonstrates greater circularity.
- Reuse rate: indicates the amount of products or components that are reused instead of discarded. A higher reuse rate contributes to circularity.
- Durability and repairability: evaluates the ability of products to be repaired and maintained, which extends their lifespan and reduces waste.

These indicators allow companies to monitor their progress toward more circular practices and identify areas for improvement.

4. Research method

In this chapter, the research planning will be presented, including the theoretical foundation, development of the proposed model, case study method, case selection criteria, and the development of the data collection instrument.

4.1 The research

The research began with the development of the theoretical foundation, which was carried out by reviewing the concepts of the circular economy (CE) and product development process (PDP), presented in Chapter 2 of this work. After analyzing these concepts, a PDP model that incorporates CE concepts was proposed, which can be seen in Chapter 3. The third step is the structuring of the research method, which is based on the case study method and will be addressed in this chapter.

4.2 Case study method

A case study can be described as an empirical research method that examines a contemporary phenomenon within its real-world context, especially when the boundaries between the phenomenon and its context are not clearly defined. This type of research deals with a unique situation in which there are more variables of interest than available data points. Therefore, it relies on multiple sources of evidence, and the data must converge, forming a type of triangulation, to provide a comprehensive understanding. In addition, it benefits from the prior formulation of theoretical propositions to guide data collection and analysis (Voss, Tsikriktsis and Frohlich, 2002; Martins, Mello and Turrioni, 2014).

A case study is a research approach that focuses on examining in depth a specific phenomenon, known as the case, within its real-world context. It may involve describing or explaining events related to that case. This investigation may be based on quantitative data, qualitative data, or a combination of both, often involving the collection of field data. There are two main types of case studies: the instrumental case study, which analyzes a single situation because of its potential applicability to other similar situations, and the intrinsic case study, which focuses on a specific situation due to its uniqueness and importance, without considering its applicability to other contexts (Yin, 2016).

Martins, Mello and Turrioni (2014) state that the case study method can be divided into three stages:

- Definition and planning: the planning stage of a case study is crucial for its effective execution. In this phase, the researcher develops the theory that will guide the research, establishing the conceptual foundations for the investigation. In addition, the research design and the cases to be studied are defined. The careful selection of cases is fundamental, and the criteria may vary according to the objectives of the study, possibly involving uniqueness, relevance, representativeness, or other pertinent factors. Careful planning at this stage is essential to guide the case study and ensure that it addresses the research questions and objectives established. This stage includes the following activities:
    - o Develop the theory;
    - Define the research design;
    - Select the cases.
- Preparation, data collection and analysis: in the preparation, data collection and analysis stage of a case study, the researcher develops a detailed research protocol outlining the data collection methods, the procedures for conducting the cases, and the analysis criteria. The process involves conducting each case, which may include interviews, observations, and document analysis, following the established protocol. As the cases are investigated, the data are systematically collected and recorded. After the completion of each case, a report is prepared describing the main findings, analyses, and conclusions. This report serves as a critical component of the overall case study narrative, providing insights that help answer the research questions and contribute to knowledge in the field of study. This stage includes the following activities:
    - Develop the research protocol;
    - Conduct the first case, second case, and additional cases;
    - Write the case reports.
- Analysis and conclusion: in the analysis and conclusion stage of a case study, the researcher focuses on establishing the reliability and validity of the findings. This involves a rigorous analysis of the collected data, both within each individual case (within-case analysis) and in comparison across

cases (cross-case analysis). During this phase, propositions are developed and tested based on the collected evidence, and the findings are compared with relevant literature to identify insights and contributions to the research field. The conclusion of the case study results in the preparation of the final report, in which the results, analyses, and interpretations are presented, highlighting the relevance of the findings in relation to the research objectives and the theoretical context. This stage is fundamental to ensure the validity and reliability of the case study and its contribution to the existing literature. This stage includes the following activities:

- Establish reliability and validity;
- Analyze the data (within and across cases);
- Develop and test propositions;
- Compare with the literature;
- Write the final report.

Figure 18 presents the activities of the case study research method.

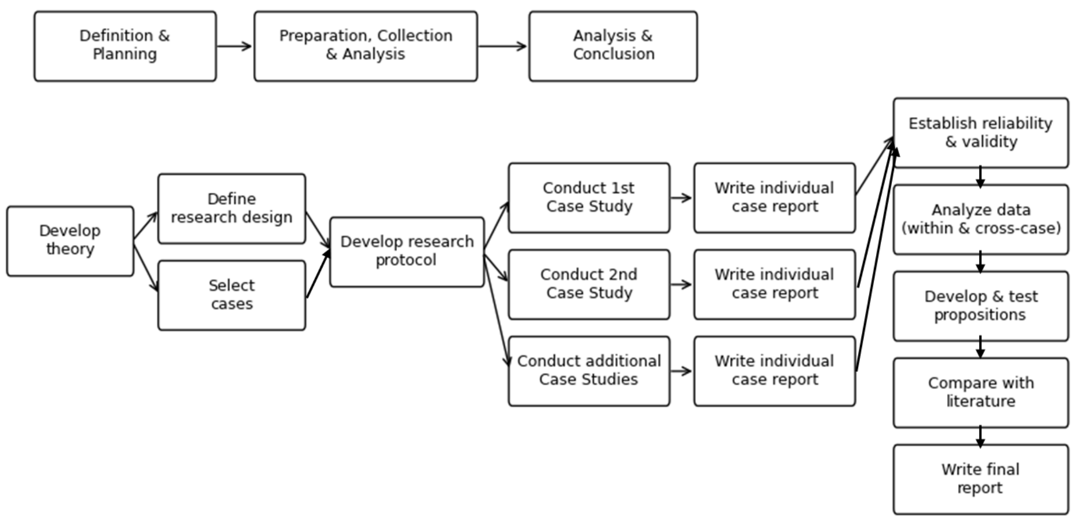

Figure 18: Case study method activities
Source: Martins, Mello e Turrioni (2014, p. 144)

4.3 Case selection criteria

Martins, Mello and Turrioni (2014) emphasize that the choice between a single case study or multiple cases must be made before data collection, considering the benefits and limitations of each approach. Single cases are appropriate for testing well-formulated theories, exploring rare cases, or revealing phenomena that were previously inaccessible, while multiple cases provide more convincing evidence and greater robustness. Each case should serve a specific purpose within the scope of the research, and the number of multiple cases depends on the desired level of certainty in the results. Literal and theoretical replications play different roles in the research, focusing on certainty and on understanding variations of the phenomenon being studied.

Defining criteria for case selection in the case study method is a fundamental step to ensure that the research is relevant, focused, and capable of answering the research questions.

For the case selection in this thesis, the following criteria were adopted:

- Adoption of circular economy practices: the most important criterion is whether the company effectively incorporates circular economy practices in its product development process and operates in the packaging sector. This may include the reuse of materials, design for recycling, extension of product lifespan, among others.
- Sustainability track record: companies with a history of commitment to sustainability and environmental responsibility.
- Innovation and creativity: selecting companies that demonstrate innovation and creativity in their circular economy approaches, such as developing new technologies, partnerships, or business models related to the circular economy.
- Implementation maturity: consideration of how long the company has adopted these circular economy practices.

4.4 Instrument for data collection

In the context of a case study, researchers employ several data collection techniques, with the structured interview being the main source of information, often complemented by unstructured interviews, personal observations, informal conversations, participation in meetings, surveys, collection of objective data, and document analysis. For the effective conduct of a case study, the creation of a research protocol is essential. This protocol not only includes the questionnaire but also establishes procedures and general guidelines to be followed in the use of the instrument, increasing the reliability and validity of the research, especially in multiple-case projects. This protocol often begins with open-ended questions and becomes more specific as the interview progresses (Voss, Tsikriktsis and Frohlich, 2002; Martins, Mello and Turrioni, 2014).

Researchers also face the decision regarding the number of respondents desired in a case study. If a key informant can reliably answer a set of questions, the research may focus on identifying and validating that person. However, when the questions cannot be answered by a single informant, due to the complexity of the subject or possible varied interpretations, conducting interviews with multiple respondents is considered in order to obtain diverse perspectives and reduce bias in the collected data (Martins, Mello and Turrioni, 2014).

To support data collection, an instrument was developed containing several questions categorized according to each phase of the proposed model presented in Figure 14.

The following questions were proposed for stage 1, scope: sustainable plastic packaging:

- What strategies or practices does the company adopt to promote the circular economy in product (packaging) development?
- Who are the main stakeholders involved in the company's circular economy strategy?
- How does the company promote awareness of the importance of the circular economy among its employees and collaborators?
- What are the company's main goals and objectives regarding the integration of circular economy principles into its product (packaging) development process?

For stage 2, business plan, the following questions were proposed:

- What types of materials and components are used in the manufacture of products (packaging), and how does the company ensure that these materials come from sustainable sources?
- What are the costs and benefits associated with implementing circular economy practices in the product (packaging) development process?

- What environmental impacts does the company aim to reduce through its circular economy practices, such as carbon emissions, use of natural resources, or toxic waste?
- What is the company’s long-term vision regarding the circular economy, and how does it plan to expand or improve its practices in the future?
- What partnerships has the company established to promote the circular economy, such as collaborations with recycling organizations, suppliers of sustainable materials, or regulatory agencies?

The following questions were proposed for stage 3, development:

- What strategies does the company use to extend the life cycle of products (packaging), such as modularity, software updates, or design for disassembly?
- Could you provide specific examples of products (packaging) developed by the company that demonstrate circular economy principles in practice?

For stage 4, testing and validation, the following questions were proposed:

- What government policies and regulations impact the company’s operations regarding the circular economy and the development of sustainable products (packaging)?
- What obstacles or challenges has the company faced when implementing circular economy practices in product (packaging) development? How were these challenges overcome?

Finally, the following questions were proposed for stage 5, launch:

- How does the company manage the life cycle of products (packaging), including recycling and reuse of materials?
- How does the company involve consumers or customers in the product (packaging) life cycle? Is there any buy-back program, refurbishment program, or incentive for returning old products?
- How does the company collect customer feedback regarding products and the circular economy approach? What changes or improvements have been implemented based on this feedback?

- What benefits are perceived by customers when purchasing products developed using a circular economy approach?
- How does the company measure and evaluate the results of its circular economy initiatives? What metrics are used to monitor progress?

4.5 Validation of the data collection instrument

With the data collection instrument prepared, it is necessary to validate it so that it can be applied in the cases. Therefore, it was sent to some experts in the field so that it could be validated.

The experts needed to meet certain requirements in order to evaluate the instrument consistently. They were required to have at least five years of experience in the field of product development and at least three years of knowledge related to the circular economy.

In this context, a brief description was prepared including the following topics: circular economy, the Stage-Gate model, the packaging sector, and the presentation of the proposed model (Figure 14). The purpose was to present the research being developed and the proposed model so that the experts could understand the work. After that, the questions developed for the data collection instrument were presented to the experts. Everything was carried out through an electronic form, and the experts were contacted by email.

Three questions were asked to the experts to evaluate the data collection instrument. These questions were:

- Is there any suggestion for improvement or adjustment (addition or removal of any question)?
- Is any question confusing or does it need to be rewritten?
- Do the formulated questions contribute to the research achieving its objectives?

Four experts evaluated the questionnaire and, based on their evaluations, the instrument could be improved.

A useful suggestion that emerged indirectly was the inclusion of numbering in the questions. In this sense, the discovery phase will be considered stage 0, and if there is a question in this phase it will be numbered as 0.1. In the first phase or stage, the questions will be numbered as 1.1, 1.2, and so on. In stage 2, the numbering will be 2.1, 2.2, and so on, and this pattern will be applied to all stages.

Some points were suggested to be addressed and some questions were recommended to be improved. Therefore, a new data collection instrument was developed in order to incorporate the evaluators' suggestions, such as adding questions to the discovery stage and moving some questions to that stage; adding new questions; separating or dividing questions into two for better understanding; clarifying some questions that were difficult to understand; and including a more detailed explanation of CFD in the question that refers to this methodology.

Table 8 presents the new data collection instrument incorporating the evaluators' suggestions.

With the data collection instrument completed, the research moved to the case study stage in the companies. The analysis of the companies and their responses can be seen in the next chapter.

Stage	Nº	Question	Comentários
0	1	How was the decision made to implement the circular economy?	
0	2	What is the company's long-term vision regarding the circular economy and how does it plan to expand or improve its practices in the future?	
1	1	What strategies or practices does the company adopt to promote the circular economy in the development of packaging?	
1	2	Who are the main stakeholders involved in the company's circular economy strategy?	
1	3	How does the company promote awareness about the importance of the circular economy among its employees and collaborators?	
1	4	How does the company promote awareness about the importance of the circular economy among collaborators of partner companies?	
1	5	What are the company's main goals and objectives regarding the integration of circular economy principles into its packaging development process?	
1	6	What barriers has the company encountered in implementing the circular economy?	
2	1	What types of materials and components are used in the manufacture of packaging?	
2	2	How does the company ensure that these materials come from renewable sources?	
2	3	What are the benefits associated with implementing circular economy practices in the packaging development process?	
2	4	What are the costs associated with implementing circular economy practices in the packaging development process?	
2	5	What environmental impacts does the company seek to reduce through its circular economy practices? (e.g., carbon emissions, use of natural resources, or toxic waste)	
2	6	What partnerships has the company established to promote the circular economy, such as collaborations with recycling organizations, suppliers of sustainable materials, or regulatory agencies?	
3	1	What strategies does the company use to extend the life cycle of its packaging? (e.g., modularity, software updates, or design for disassembly)	
3	2	Could you provide specific examples of packaging developed by the company that demonstrate circular economy principles in practice?	
3	3	How do you evaluate the use of CFD (Circular Function Deployment) in your company? (see separate explanation)	
4	1	What government policies and regulations impact the company's operations regarding the circular economy and the development of sustainable packaging?	
4	2	Are there clients who require the development of sustainable packaging?	
4	3	How was this request for sustainable packaging made by the clients?	
4	4	What obstacles or challenges has the company faced when implementing circular economy practices in the development of packaging?	
4	5	How were these challenges overcome?	
5	1	How does the company manage the life cycle of packaging, including recycling and reuse of materials?	
5	2	Does the company carry out any monitoring regarding the relationship between customers and the circular economy?	
5	3	How does the company involve consumers or customers in the life cycle of packaging? Is there any buy-back program, refurbishment program, or incentive for returning used packaging?	
5	4	How does the company collect customer feedback regarding its packaging and the circular economy approach? What changes or improvements have been implemented based on this feedback?	
5	5	What benefits are perceived by customers when purchasing packaging developed using a circular economy approach?	
5	6	How does the company measure and evaluate the results of its circular economy initiatives?	
5	7	What metrics are used to monitor the progress of circular economy initiatives?	

Table 10: Logics for value creation in the business model
Source: Prepared by the author

5. Case study

In this chapter, the analysis of the cases selected for this study will be presented. The case study method was applied in two companies from the plastic packaging sector. A small number of cases was chosen so that they could be explored in greater depth. First, a description of the companies will be presented; subsequently, each case was analyzed separately (within-case analysis), and finally a comparative analysis between the two cases was conducted (cross-case analysis).

5.1 Description of the companies

5.1.1 Description of Company A

Founded more than two decades ago, this Minas Gerais–based industry has specialized in the manufacture of flexible packaging, with strong operations in the food, cosmetics, personal care, cleaning, health, and wellness segments. With a solid structure that continues to expand, the company has established its position in the national market by providing customized and technically advanced solutions for the protection, presentation, and preservation of products. Its operations stand out due to its mastery of technologies such as lamination, coextrusion, and high-definition printing, meeting demands ranging from small production runs to large industrial volumes.

Its portfolio is broad and includes stand-up pouch packaging with or without zipper closures, high-barrier laminated films, metallized structures with distinctive visual appeal, shrink labels, security seals, and nylon-poly solutions for products requiring greater thermal and mechanical resistance. The company also develops materials with specific barriers against oxygen, moisture, and light, which are essential for preserving the integrity of perishable and environmentally sensitive products. The options include films with matte, glossy, varnished, and laminated finishes, as well as accessories such as valves, spouts, and gussets, allowing both aesthetic and functional customization of packaging.

The product catalog of this manufacturer is carefully developed to meet multiple technical and market requirements, focusing on performance, aesthetics, and functionality while also considering circular economy principles. One of its flagship products is stand-up packaging, which combines reinforced structures with zipper options, dispensing spouts, and valves, making them ideal for products that require convenience in consumption and strong shelf presence. High-barrier laminated films are also prominent, designed to preserve the flavor, aroma, and freshness of foods or cosmetics that are sensitive to light and oxidation, with finishing options such as matte, glossy, or soft-touch. Meanwhile, shrink solutions ensure complete adherence to the product, enhancing security and perceived value, especially in applications that require tight sealing and a clean presentation.

Another technical differentiator is the development of multilayer structures that combine materials such as PET (polyethylene terephthalate), PE (polyethylene), BOPP (biaxially oriented polypropylene), nylon, and polyester in specific combinations for each type of application. These structures are used both in rolls for automatic packaging and in ready-to-fill packaging for manual or semi-automatic filling. The company also offers labels, seals, and tags with high-definition printing, adapted to different surface types and formats, with resistance to friction, moisture, and temperature variations. This flexibility allows packaging not only to protect and preserve its contents but also to reinforce brand positioning through visually impactful and technically reliable solutions.

With robust production capacity and well-structured processes, the company maintains operations distributed across units dedicated to production, storage, and logistics, all integrated to ensure agility in service and consistency in quality. The organizational culture values continuous innovation, people development, and the pursuit of solutions that add real value to packaged products. There is a strong emphasis on brand aesthetics, leading packaging to be conceived not only as protection but also as a vehicle for sales, positioning, and differentiation at the point of sale.

The clients served operate in markets that demand high standards of food safety, sanitary certifications, traceability, and technical compliance. To meet these requirements, the company invests in modern equipment, quality control laboratories, and specialized teams in materials engineering, design, and printing technology. This technical versatility enables the company to serve both regional businesses and large national corporations with the same attention to detail and commitment to deadlines.

Despite its growth, the company maintains a strong identity connected to its origins, preserving values such as hard work, appreciation of people, transparency, and respect for the trust of its business partners. Its location in the state of Minas Gerais contributes strategically to national distribution, enabling optimized logistics routes and easier access to various consumer markets across the country. The company continues to invest in physical expansion, new products, and packaging technologies that combine technical performance, sustainability, and visual impact.

5.1.2 Description of Company B

With more than four decades of operations, this company is one of the global leaders in the plastic packaging sector, standing out for its innovation, sustainability, and international reach. Its headquarters is located in the state of São Paulo, from where it coordinates operations that extend across several countries in the Americas and Europe.

Specialized in the manufacturing, processing, and recycling of plastic materials, the company has a broad product portfolio that includes flexible and rigid packaging, technical films, bags, PET preforms, bottles, jars, containers, and plastic caps. It serves several industrial sectors such as food and beverages, cosmetics, pharmaceuticals, automotive, construction, and personal hygiene products.

The company’s production structure includes dozens of industrial plants and logistics centers strategically located to ensure operational efficiency and rapid response to regional demands. In Brazil, its facilities are distributed across important industrial hubs, providing high production capacity and a wide range of solutions.

The products developed cover a wide variety of applications, ranging from coextruded and laminated technical films that offer high barrier protection for food and pharmaceuticals to rigid packaging such as bottles, jars, and containers that ensure safety and practicality in storage and transportation. The company also stands out for manufacturing PET preforms for bottles, as well as plastic caps that ensure reliable sealing and ease of use. A significant portion of its portfolio is dedicated to sustainable solutions, including packaging made from recycled materials and designs that facilitate post-consumer recycling.

Its customer base is diversified and includes large and medium-sized companies from both industrial and commercial sectors. The company serves well-known brands in the food, beverage, cosmetics, pharmaceutical, automotive, and personal hygiene segments, as well as firms in the construction and cleaning sectors.

Its service approach focuses on providing customized solutions that meet the specific requirements of each client, offering technical support for packaging development that integrates functionality, aesthetics, and sustainability. This close relationship allows the company to build long-term partnerships and establish itself as a strategic supplier within its clients' production chains.

One of its major differentiators is its strong commitment to sustainability and the circular economy. The company was a pioneer in the use of post-consumer recycled PET resin approved for food contact, making significant investments in technologies for plastic waste recycling and the reduction of environmental impact. It has established ambitious goals to progressively recycle a substantial portion of the plastic it produces, aiming for full carbon emission neutrality by 2040.

The company participates in international agreements and environmental pacts, demonstrating social and environmental responsibility, while also operating with innovative processes such as technologies for removing inks and contaminants from used plastics, thereby increasing recycling efficiency.

To strengthen its market presence and optimize its operations, the company consolidated several brands and businesses under a single identity, which expanded its capacity for innovation and the supply of customized products tailored to the specific needs of its customers.

With a workforce of thousands of employees, the company maintains a strong focus on technical excellence and sustainable development, continuously investing in research, development, and strategic partnerships to deliver integrated and high-quality plastic packaging solutions for different market segments.

5.2 Within-case analysis

5.2.1 Case of Company A

Based on the questions that were developed and used in the data collection instrument (presented in Sections 4.4 and 4.5 of this thesis), this section presents the analysis of Company A in relation to its alignment with the proposed model.

The professional responsible for supporting the case study within the company works in the research and development department and has more than five years of experience in this area.

Regarding the question about the decision to implement the circular economy (question 0.1), it can be stated that Company A incorporates Circular Economy principles consistent with those presented in the Theoretical Framework (Chapter 2 of this thesis), particularly concepts such as recycling, reuse, reverse logistics, resource efficiency, and value regeneration.

Company A highlights robust investments in technology, innovation, and the development of circular products, aiming to anticipate trends and position itself as a leader in the sector, while also aligning with the principle of maximizing the utility and value of resources. This positioning is consistent with what Sandoval, Jaca, and Ormazabal (2018) and Hofstra and Huisingh (2014) describe as cyclical and regenerative eco-innovations, in which circularity is achieved through solutions that not only reduce impacts but also create additional value for the environment and society. Furthermore, by emphasizing its role in anticipating trends and leading the sector, the company aligns with the vision of the Ellen MacArthur Foundation (2019), which defines the circular economy as a restorative and regenerative model that keeps materials and products at their highest level of utility and value.

Regarding the long-term vision and expansion of the circular economy (question 0.2), it is possible to establish a correlation between the company's long-term perspectives and the circular economy concepts discussed in the theoretical framework (Chapter 2 of this thesis). Although the strategies present different emphases, they are aligned with the principles and guidelines of circularity and sustainability.

Company A projects its future activities based on three main pillars: expanding the use of recycled and renewable raw materials, investing in advanced technologies, and developing products aligned with the circular economy. This perspective directly reflects the principles presented by the Ellen MacArthur Foundation (2019), according to which the circular economy is based on eliminating waste and pollution, keeping materials in use, and regenerating natural systems. In addition, the mention of reverse logistics and post-consumption programs is theoretically supported by Genovese et al. (2017), who emphasize the importance of such mechanisms in closing material loops. Continuous investment in innovation and environmental certifications also aligns with the concept of regenerative eco-innovations described by Hofstra and Huisingh (2014), which aim not only to reduce environmental damage but also to generate long-term value.

The analysis of the strategies adopted by the company (question 1.1) reveals different pathways to promote the circular economy in packaging development, and the company demonstrates points of convergence with the concepts presented in the theoretical framework (Chapter 2 of this thesis).

Company A presents a structured set of practices directly aligned with the principles of the circular economy. The development of Ecoprime, the first 100% recyclable and shrinkable packaging in Brazil, exemplifies the application of circular design principles emphasized by the Ellen MacArthur Foundation (2019), which highlight the importance of designing packaging to facilitate reuse, recycling, and disassembly. The use of recycled resins, reduction in film thickness, and the selection of polymers better suited for recycling reflect the practical application of the 3Rs (reduce, reuse, and recycle) highlighted by Ghisellini, Cialani, and Ulgiati (2016), and also represent the pursuit of resource efficiency discussed by Wu et al. (2014).

The investment of 30 million in specialized machinery and the emphasis on strategic partnerships with recyclers and certified suppliers are consistent with the perspective of cyclical and regenerative eco-innovations, which aim to consolidate new production models capable of closing material loops (Sandoval, Jaca, and Ormazabal, 2018). Therefore, the strategy adopted by Company A positions the company as a reference in the adoption of proactive and integrated practices, bringing theory and practice closer together toward a circular business model.

The identification of the main stakeholders involved in the circular economy strategy (question 1.2) is essential, since the circular economy assumes the integration of different actors along the value chain. As presented in the theoretical framework (Chapter 2 of this thesis), the circular economy depends on articulation among micro-level actors (companies and consumers), meso-level actors (integrated value chains), and macro-level actors (cities, regions, and governments), with stakeholders playing a fundamental role in enabling circular flows of materials, energy, and information (Sandoval, Jaca, and Ormazabal, 2018).

In Company A, stakeholders are divided into internal and external groups. Internally, the board of directors and technical departments (R&D, Production Engineering, Quality, and Marketing) stand out, as they are responsible for planning and executing sustainable solutions. Externally, the company maintains relationships with certified suppliers, recyclers, cooperatives, laboratories, and environmental certification bodies, ensuring sustainable inputs and compliance with environmental standards. In addition, customers are recognized as key actors, since their demands drive the development of innovative solutions, such as Ecoprime packaging. This set of relationships reflects what the Ellen MacArthur Foundation (2019) defines as a systemic approach to circularity, in which companies, suppliers, customers, and certification organizations collaborate to keep products and materials circulating at their highest possible value.

Internal awareness (related to question 1.3) is a central element for the effective implementation of the circular economy, since, according to Khan and Haleem (2021), the transition from linear to circular models requires not only technological changes but also cultural and behavioral changes. In this sense, it can be observed that Company A has developed specific strategies to raise awareness among its employees and promote engagement in circular practices.

At Company A, awareness is promoted in a structured way through periodic training sessions that address fundamental concepts of the circular economy, sector innovations, and strategic reasons for adopting sustainable practices. In addition, the company disseminates information in everyday work activities, especially in areas related to production and product development, contributing to the construction of an organizational culture of environmental responsibility. This practice aligns with the concept of corporate education and engagement of internal stakeholders described by Dokter, Thuvander, and Rahe (2021), in which continuous learning and knowledge dissemination are essential for consolidating circular behaviors.

Promoting awareness among employees of partner companies (question 1.4) constitutes a fundamental aspect of the circular economy, because, as highlighted by Khan and Haleem (2021), the transition from linear to circular models requires not only technological innovation but also multisector cooperation and cultural changes that involve the entire value chain.

At Company A, partner awareness is mainly promoted through technical dialogue during negotiations and joint projects, with an emphasis on presenting the advantages of solutions such as Ecoprime. When necessary, the company provides guidance regarding certifications, trends, and market requirements through a process tailored to the profile of each partner. This strategy is consistent with the concept described by Wang, Burke, and Zhang (2022), who point out that training and knowledge dissemination are essential tools for enabling circular practices. In addition, by supporting the certification of suppliers and clients, Company A reinforces the importance of creating reliable markets for recycled materials, an aspect highlighted by Genovese et al. (2017) as central to overcoming acceptance barriers.

The definition of clear goals and objectives is a fundamental element for the effective integration of the circular economy into business processes (question 1.5). According to Pauliuk (2018), progress toward circularity depends not only on the adoption of technical practices but also on the formulation of measurable strategic commitments capable of guiding investments, innovation, and stakeholder engagement. In this sense, Company A reports the existence of structured objectives that guide its actions in packaging development, although with different emphases.

Company A establishes specific goals directly aligned with circular economy principles, such as increasing the use of certified recycled raw materials, developing and expanding 100% recyclable packaging (for example, Ecoprime), reducing raw material consumption through thickness and process optimization, and seeking environmental certifications. The company also emphasizes raising awareness among customers and partners, encouraging the adoption of sustainable packaging throughout the production chain. These goals are consistent with the principles of the 3Rs (reduce, reuse, recycle) described by Ghisellini, Cialani, and Ulgiati (2016), as well as with the concept of regenerative eco-innovation presented by Hofstra and Huisingh (2014), which emphasizes the development of solutions that not only minimize impacts but also create additional value for the production system. Furthermore, the emphasis on certification and transparency responds to what Khan and Yu (2021) identify as the need for institutional credibility to foster markets for recycled inputs.

The implementation of the circular economy in companies within the packaging sector faces several barriers that go beyond technical aspects, also encompassing economic, cultural, and structural factors (question 1.6). The literature on the subject highlights that the transition to circular models is a gradual and challenging process, marked by obstacles related to high costs, technological limitations, lack of infrastructure, and behavioral resistance (Jugend et al., 2020; Khan and Haleem, 2021; Loon, Diener, and Harris, 2021).

At Company A, the main barrier identified was the high cost of investments in state-of-the-art equipment, development of new products, and acquisition of certified recycled raw materials. This difficulty corresponds directly to what the literature identifies as one of the main barriers to the circular economy: the economic imbalance between virgin and recycled inputs, where recycled material tends to be more expensive and often less competitive (Gagnon et al., 2022). In addition, Company A reported technical challenges in adapting industrial processes and ensuring the quality of circular packaging, an obstacle already discussed by Hofstra and Huisingh (2014), who point to the need for advances in eco-innovation to overcome performance limitations. Another point mentioned by the company was the lack of prepared national suppliers and the initial resistance of clients to the additional cost of sustainable packaging. These aspects reinforce the argument of Wang, Burke, and Zhang (2022), according to which circularity depends on the articulation of the entire value chain and not only on isolated efforts by companies.

The selection of materials and components used in the manufacture of packaging is one of the central aspects for the implementation of the circular economy (question 2.1), since it determines both the possibilities for reuse and recycling and the environmental impacts associated with the product life cycle. As emphasized by Ofterdinger, Dlugoborskyte, and Herstatt (2021), the selection of materials that are more compatible with recycling processes is decisive for enabling circularity, while Salvador et al. (2020) highlight that decisions made during the design stage and in the selection of inputs condition the entire subsequent environmental performance.

At Company A, there is a clear prioritization of polyolefin resins, especially polyethylene (PE) and polypropylene (PP), due to their high recyclability and applicability in flexible packaging. The use of high-molarity polymers, selected because they facilitate the recycling process and increase the efficiency of material recovery, is also aligned with the principle of design for circularity advocated by the Ellen MacArthur Foundation (2019). This approach demonstrates an explicit concern with maximizing recyclability without compromising the functionality of the packaging, an aspect considered fundamental in the literature on regenerative eco-innovation (Hofstra; Huisingh, 2014).

Ensuring that the materials used in packaging manufacturing come from renewable or sustainable sources is one of the greatest challenges of the circular economy, particularly in sectors highly dependent on fossil derivatives such as plastics (question 2.2). The literature indicates that the transition to renewable raw materials requires both technological innovation and governance and traceability mechanisms, and is also subject to barriers related to availability, cost, and regulation (Gagnon et al., 2022; Laurenti et al., 2015; Mohagheghian et al., 2021).

At Company A, the strategy to ensure renewable and recycled sources is based on the careful selection of suppliers that explicitly adopt sustainable practices and on requesting documentation proving the origin of materials whenever possible. Although the company recognizes market limitations and the impossibility of fully tracing all inputs in a standardized manner, it seeks to align its procurement practices with global sustainability trends and contribute to a more responsible production chain. This practice is consistent with the principle of transparency and traceability highlighted by Dumée (2022) and Khan et al. (2021), who consider supply chain control to be an essential element in ensuring credibility and reliability in the use of circular materials.

The implementation of circular economy practices in packaging development generates benefits across multiple dimensions: environmental, economic, social, and organizational (question 2.3). The literature shows that the application of circularity principles makes it possible to reduce environmental impacts, extend product life cycles, preserve the value of materials, and create new business opportunities (Batwara et al., 2022; Evrard et al., 2021; Gagnon et al., 2022; Jugend et al., 2020).

In this context, Company A emphasizes that circularity generates direct gains in production efficiency through the reuse of resins in less complex applications, the reduction of virgin raw material consumption, and the optimization of internal processes. Although the company acknowledges that investments in technologies and recycled inputs represent a high initial cost, it highlights that such practices result in medium- and long-term benefits, both economically and in strengthening institutional reputation, since consumers and partners have increasingly valued sustainable initiatives.

The literature on the circular economy indicates that the costs (question 2.4) associated with its implementation are multifaceted and not limited to the initial expenditure on equipment. They include investments in machinery and infrastructure; additional operational costs such as energy, maintenance, and recycled inputs; transaction costs (certifications, audits, contracts with suppliers and recyclers); adaptation and quality costs (process control and product validation to maintain performance); and organizational costs (training, changes in procedures, and project management). These costs tend to be higher in the short term, and the perception of financial return usually occurs only in the medium to long term, especially if there is no purchasing scale for secondary inputs or regulatory incentives that internalize environmental externalities (Gagnon et al., 2022).

In the report from Company A, the costs are clearly reflected in the form of significant investments in assets and process adaptations: the acquisition of specific machinery to process recycled resins, modifications to the production plant, the hiring of specialized consulting services, and the development of products (e.g., Ecoprime). The company quantified this effort at approximately 30 million, a figure that includes direct investment, engineering expenses, and likely pre-operational costs (commissioning, testing, and validation). In addition, there are recurring costs resulting from the purchase of special resins and certifications, as well as the risk of cost increases (e.g., energy consumption for recycling, losses due to scrap or reprocessing) until processes and suppliers stabilize. These elements reveal a profile in which the initial financial factor is decisive; without scale or external support, the payback period depends on the company's ability to transfer efficiency gains and on the recognition of value by customers (price and acceptance).

The literature on the circular economy and environmental sustainability highlights that organizations seek to reduce impacts in three main areas:

i. solid waste, through recycling and reuse of materials, avoiding improper disposal;
ii. use of natural resources, focusing on water and energy efficiency; and
iii. carbon emissions, associated with production, transportation, and disposal (Brazil, 2010; Brazil, 2022).

The integration of these aspects into the packaging production process is particularly relevant due to the sector's strong dependence on fossil-based plastics and the significant volume of waste generated. In this sense, analyzing environmental impacts and how the company seeks to minimize and reduce them is important (question 2.5).

In the case of Company A, the main environmental impacts targeted for reduction are related to waste management and water efficiency. The company prioritizes the reuse of materials, reducing the amount of industrial waste generated, and implements water treatment and reuse systems in its production process. Although it mentions the reduction of CO_2 emissions as part of its objectives, the emphasis is placed on waste control practices and the rational use of natural resources, aligning with a more operational and pragmatic management profile. This approach reflects an initial alignment with circularity principles, although still with less scope in relation to global carbon and energy metrics.

Examining partnerships between companies and suppliers is important for the circular economy (question 2.6). The literature on the circular economy emphasizes that successful implementation strongly depends on interorganizational collaboration, since no company can independently close material loops and promote a truly sustainable supply chain. Partnerships with recyclers, suppliers of sustainable raw materials, cooperatives, and regulatory bodies are identified as fundamental mechanisms for enabling the flow of secondary materials and legitimizing environmental practices in the eyes of the market and society (Elia, Gnoni, and Tornese, 2017; Ellen MacArthur Foundation, 2019; Khan and Haleem, 2021; Wang, Burke, and Zhang, 2022).

In the case of Company A, partnerships are mainly concentrated with recyclers, which play an essential role in enabling the use of recycled materials in second-line packaging. This collaboration allows plastic waste that would otherwise be discarded to return to the production process, reinforcing circularity and contributing to the reduction of environmental impact. Although the company does not mention formal certifications or partnerships with regulatory bodies, Company A’s actions illustrate a practical integration with actors in the recycling chain, strengthening its ability to align production efficiency with environmental objectives.

Extending the life cycle (question 3.1) of packaging is one of the central principles of the circular economy, as it helps reduce the demand for virgin raw materials, minimize waste, and optimize the use of natural resources. The literature indicates that this strategy can be achieved through different mechanisms: intelligent design (modularity, ease of disassembly, inclusion of zippers or viewing windows), material durability (resistance and protection of contents), consumer reuse (e.g., ice cream or margarine containers reused in other contexts), and post-use value recovery (ease of recycling or energy recovery) (Amend et al., 2022; Asif et al., 2021; Bressanelli et al., 2020; Joustra, Flipsen, and Balkenende, 2021).

In the case of Company A, the main strategy is centered on the development of more resistant and higher-quality packaging, enabling more than one cycle of use. Although it does not detail specific redesign mechanisms, the company adopts practices that reinforce durability as a vector of circularity, encouraging reuse and reducing the premature generation of waste. This approach is still relatively traditional, but it reflects an effort to align the product portfolio with sustainability demands through material robustness and packaging reliability.

The adoption of circular economy practices in the packaging sector fundamentally depends on the development of concrete solutions that demonstrate how theoretical principles are translated into real products (question 3.2). The literature emphasizes that the effective application of circularity occurs through packaging designed to be recycled, reused, or reintroduced into the production cycle, reducing dependence on virgin raw materials and minimizing environmental impacts (Ellen MacArthur Foundation, 2019; Genovese et al., 2015). In this way, practical examples of circular packaging play a central role not only in aligning with environmental objectives but also in building credibility with the market and consumers.

At Company A, several initiatives stand out. One notable example involves cheese packaging that, after consumption, can be collected, recycled, and transformed into new packaging, such as packaging for ice. This strategy represents a direct reuse cycle, clearly demonstrating circularity in practice. Another highlight is Ecoprime, recognized as the first 100% recyclable shrink packaging in Brazil. This product was specifically developed to enable its return to the production chain without significant material loss, demonstrating a commitment to sustainable innovation. In addition, the company promotes the internal reuse of plastic waste, transforming it into secondary product lines such as garbage bags or packaging for plant seedlings, reinforcing the idea of maximizing the use of available resources.

The use of structured methodologies, such as Circular Function Deployment (CFD), can be a determining factor for the systematic incorporation of circular economy principles into the packaging development process (question 3.3). This tool, inspired by Quality Function Deployment (QFD), seeks to integrate circularity criteria from the early stages of product design, promoting greater alignment between innovation, sustainability, and market requirements. However, it is observed that the application of this methodology is still limited within the sector, either due to a lack of conceptual familiarity or practical limitations in adapting it to internal processes (Vimal et al., 2022).

In the case of Company A, the response is straightforward: the CFD methodology is not used in its processes. This indicates that although the company adopts concrete circularity practices in its products, there is no formal systematization based on structured frameworks such as CFD. From an academic perspective, this absence may represent both a limitation—by reducing the predictability and control of the circularity integration process—and an opportunity, since the future adoption of CFD could further strengthen the sustainability strategies already in place.

Regulatory compliance plays a strategic role in advancing the circular economy applied to packaging, as it guides both the limits and the opportunities for innovation. The plastics and packaging sector, in particular, is subject to a legal framework that combines environmental, public health, and market policies, reflecting growing global concerns about waste, recycling, and pollution reduction (question 4.1).

In the case of Company A, the company positions itself in accordance with Brazil's National Solid Waste Policy (Política Nacional de Resíduos Sólidos – PNRS), which establishes guidelines for proper waste disposal and the promotion of reverse logistics. In addition to this central legislation, Company A must comply with state regulations and technical standards, such as those issued by ABNT, which define quality and safety parameters. Another crucial aspect is compliance with the requirements of Anvisa, particularly for packaging that comes into contact with food, ensuring sanitary safety. The company recognizes that the Brazilian regulatory environment is still evolving and that new legislative initiatives may intensify requirements related to circularity.

The question regarding the demand for sustainable packaging by clients reveals different perceptions among the companies investigated (question 4.2). Company A highlighted that there is growing interest from large brands and exporters, but practical adoption is still limited by additional costs. This reality aligns with theoretical discussions in the literature, which identify barriers on both the demand and supply sides. Zikopoulos (2022) points out that consumer environmental awareness is still insufficient to sustain an effective market transformation, explaining why, even when interest exists, the willingness to pay additional costs remains limited.

Another point of connection relates to consumer perceptions of value regarding sustainable products. Pretner et al. (2021) emphasize that although some consumers perceive positive value in circular products, others associate them with lower quality, especially when recycled materials are involved, which influences purchasing decisions. This reinforces the challenge reported by Company A, which identifies customer interest but faces difficulties in converting that interest into practical adoption.

Requests for sustainable packaging (question 4.3) can occur in different ways and reflect the growing pressure exerted by clients and society on companies.

In the case of Company A, such requests arise both from contractual requirements and environmental certification demands, especially when dealing with large clients or export operations, as well as during negotiations or commercial meetings. In other situations, they appear as curiosity or direct suggestions from clients.

Another important point is that Company A also anticipates these demands through internal initiatives, such as the development of Ecoprime, which was created by the company's management to respond to anticipated future market trends. This aligns with the literature emphasizing the role of both external demand and internal strategic initiatives in advancing circularity (Geissdoerfer et al., 2017).

This reality connects to the theoretical framework, which highlights that the circular economy depends on pressures operating at different levels: micro (companies and consumers), meso (production chains and recycling networks), and macro (public policies and regulations), all functioning as drivers of circular practices (Sandoval, Jaca, and Ormazabal, 2018). In this way, client demand may take the form of formal requirements, such as contracts and certifications, or informal pressures, such as consumer trends and the pursuit of a positive environmental image.

The adoption of circular economy practices in packaging development presents obstacles (question 4.4) that vary according to each organization's trajectory and its level of maturity regarding sustainability.

In the case of Company A, the main challenges reported are associated with high investment costs in technologies, machinery, and certified recycled raw materials, as well as technical barriers to ensuring that sustainable packaging maintains the same performance as conventional packaging. Logistical difficulties were also mentioned, particularly regarding the acquisition of inputs and the adaptation of internal processes, as well as some initial resistance from the market, both from suppliers and clients.

Overcoming these challenges (question 4.5) in the implementation of circular economy practices in the packaging sector depends on strategic, economic, and cultural factors, which vary according to each company's trajectory.

In the case of Company A, the report shows that planned financial investment was the main tool used to enable the adoption of sustainable practices. According to the company, allocating resources to new technologies, materials, and processes required courage and long-term vision, but it proved decisive for taking the first steps and sustaining the changes needed toward circularity. This demonstrates that despite high initial costs, organizations that view sustainability as a strategic driver can transform obstacles into opportunities for competitive differentiation.

These experiences align with the literature presented in the theoretical framework (Chapter 2 of this thesis), which describes barriers and strategies for overcoming them. Ghisellini, Cialani, and Ulgiati (2016) point out that investment in innovation and new technologies is essential for overcoming technical and market limitations associated with circularity. Likewise, Gagnon et al. (2022) emphasize that high costs and the lack of consolidated demand require strategic vision and financial planning, confirming the posture adopted by Company A.

The way companies manage the life cycle of packaging (question 5.1) reveals different stages of maturity regarding the circular economy.

In the case of Company A, it is observed that there is still no structured reverse logistics program or formal incentives for packaging return. Responsibility for the final destination remains with clients, and the company's role is limited to monitoring trends and evaluating future possibilities, especially in light of potential new legislation. This position demonstrates a more reactive rather than proactive approach, in which circularity has not yet been fully integrated into operational strategy.

Monitoring customer relationships with the circular economy (question 5.2) remains a sensitive point within the analyzed business practices.

In the case of Company A, there is no structured system to track the final destination of packaging. The absence of specific legal requirements mandating such monitoring means that the company does not adopt formal mechanisms to trace disposal or verify whether packaging is effectively reinserted into recycling chains. This indicates that circularity is understood in a limited way, restricted to the production stage and not extended to the consumption and post-consumption phases.

This point aligns with the theoretical framework, which emphasizes that the circular economy should not be limited to companies but must involve the entire value chain, including consumers, recycling cooperatives, and regulatory bodies. Dantas et al. (2021) highlight that the absence of systematic monitoring of product use and disposal represents one of the main obstacles to the effectiveness of the circular model, generating gaps in the reuse cycle. In addition, Genovese et al. (2015) and Wang, Burke, and Zhang (2022) emphasize that feedback and traceability mechanisms are essential for companies to redesign strategies, identify bottlenecks, and promote circularity at a systemic level.

Consumer involvement in the packaging life cycle (question 5.3) is a fundamental aspect for the effectiveness of the circular economy, since active customer participation enables the closing of reuse cycles and reduces environmental impacts.

In the case of Company A, it was observed that programs aimed at encouraging packaging return and reuse have already been evaluated. However, participation was considered low, mainly because the company's customer base consists largely of micro and small entrepreneurs, who often lack the structure or interest to participate in such initiatives. This limitation means that the company's efforts are still at an exploratory stage, without robust reverse logistics or buyback programs fully established. Company A has evaluated reverse logistics programs but encountered low participation from clients, particularly micro and small entrepreneurs. This finding confirms the literature, which highlights the difficulty of engaging small actors in circular economy initiatives (Wang, Burke, and Zhang, 2022).

The process of collecting customer feedback (question 5.4) is a key element for aligning business practices with circular economy principles, as it allows companies to understand expectations, identify barriers, and guide improvements in products and processes.

In the case of Company A, feedback is mainly obtained through commercial service interactions, direct conversations with clients, and post-sale follow-up. This proximity enables a clearer understanding of how packaging is perceived in the market and what adjustments are necessary. As a result of this process, the company has implemented improvements in its line of sustainable and recyclable packaging, seeking to adjust characteristics such as practicality, resistance, and environmental communication in order to reinforce both functionality and commitment to sustainability.

The benefits perceived by clients (question 5.5) when acquiring sustainable packaging are mainly related to strengthening the positive image of their brands and enhancing environmental appeal among consumers and society. This finding aligns with the literature, which indicates that circular products can add intrinsic value by diverting waste from landfills while also meeting the environmental beliefs and values of certain consumer groups (Evrard et al., 2021; Pretner et al., 2021).

For Company A, the main benefits perceived by its clients include the strengthening of brand image, increased commercial appeal, and opportunities for competitive differentiation. The use of sustainable packaging is viewed as a value-adding factor, allowing companies to meet the expectations of more environmentally conscious consumers as well as the requirements of large buyers or export markets. In addition, practical benefits are also perceived, such as improved functionality and, in some cases, long-term cost reductions associated with process optimization and the use of recyclable materials.

The measurement and evaluation of the results of circular economy initiatives (question 5.6) are fundamental elements for understanding the effectiveness of these practices and guiding strategic adjustments.

Company A adopts a more simplified model based on internal surveys and periodic analyses of the use of recycled materials and the performance of its sustainable packaging. Although this process is not highly structured, it allows the company to track key indicators related to the adoption of recycled inputs and the efficiency of its circular solutions, creating a cycle of monitoring and continuous improvement.

The literature reinforces the importance of measurement within the circular economy context, highlighting that only through clear indicators is it possible to verify environmental, economic, and social gains (Pauliuk, 2018). As pointed out by Figge et al. (2018), the absence of consolidated metrics is one of the main barriers to the effective implementation of circularity, emphasizing the need for continuous improvement in monitoring approaches.

Monitoring the progress (question 5.7) of circular economy initiatives requires the use of metrics capable of translating corporate advances into measurable results. The metrics used to monitor progress include tons of recycled plastic, percentage of recycled content in packaging, reduction in carbon intensity per ton produced, and the volume of virgin raw materials avoided. These indicators are consistent with the literature, which highlights the relevance of measurements associated with circularity, material flows, resource longevity, and monetary value (Niero and Kalbar, 2019; Figge et al., 2018).

In the case of Company A, current practices are centered on observing indicators related to the use of recycled materials and the performance of its sustainable solutions. Although these data are more qualitative and primarily intended for internal monitoring, they provide support for guiding future actions and aligning the company's strategies with the growing market expectations regarding sustainability.

5.2.2 Case of Company B

Based on the questions that were developed and used in the data collection instrument (presented in Sections 4.4 and 4.5 of this thesis), this section presents the analysis of Company B in relation to its alignment with the proposed model.

The professional from the company who acted as the respondent works in the research and development department and has more than five years of experience in this area.

Regarding the question about the decision to implement the circular economy (question 0.1), it can be observed that Company B incorporates Circular Economy principles consistent with those presented in the Theoretical Framework (Chapter 2 of this thesis).

Company B has a history linked to recycling and reverse logistics, initially focused on PET bottles and circularity through mechanical recycling and, subsequently, chemical recycling, which enables the complete closure of material loops. This approach is strongly related to the principles of recycling, reuse, and reverse logistics highlighted in the theoretical framework (Chapter 2 of this thesis) as central to the circular economy.

This account is directly connected with the principles of the circular economy presented by Ghisellini, Cialani, and Ulgiati (2016), who emphasize the centrality of the 3Rs (reduce, reuse, recycle), and with the definition of reverse logistics as an essential instrument for reinserting materials into the production cycle (Genovese et al., 2017; Wang, Burke, and Zhang, 2022). The company's evolution toward chemical recycling further reinforces the relationship with the concept of closing material loops, discussed by Korhonen et al. (2018) and the Ellen MacArthur Foundation (2019).

With regard to the long-term vision and the expansion of the circular economy (question 0.2), a relationship can be identified between the company's strategic direction and the circular economy foundations presented in Chapter 2 of this thesis. It is evident that the strategic approaches adopted by Company B converge toward circularity principles and sustainability-oriented guidelines.

Company B presents a long-term vision linked to planning structured around temporal milestones (5, 10, and 20 years), focusing on broad sustainability and on the circular economy as an integral part of this agenda. The company's report reinforces practices such as the use of renewable energy and the replacement of fossil-based inputs, aligning with the principles highlighted by Ghisellini, Cialani, and Ulgiati (2016), who advocate the transition to renewable energy as a key factor of circularity. Furthermore, the company's statement that it has historically been "one step ahead of the market" in adopting recycling practices indicates the incorporation of circular and innovative business models, as pointed out by Elia, Gnoni, and Tornese (2017), who emphasize the need to adapt business models in order to sustain circular practices in the long term.

The analysis of the strategies adopted by the company (question 1.1) reveals distinct approaches to fostering the circular economy in packaging development.

In this regard, Company B demonstrates an approach more conditioned by the market context, particularly due to the cost barrier associated with implementing circular solutions. The company's strategy consists of offering more sustainable alternatives to clients, such as monomaterial packaging, certified materials, and structures with greater recyclability, even when the final choice still falls on conventional structures due to price considerations. This practice is consistent with the challenges identified by Ghisellini, Cialani, and Ulgiati (2016), who highlight high costs, lack of infrastructure, and low scale of recycled materials as barriers to the full implementation of the circular economy. Nevertheless, the company's position of always presenting clients with a more circular alternative, even if only partially, aligns with the perspective of gradual transition toward the circular economy described by Dantas et al. (2021), according to which systemic changes require time, adaptation, and market acceptance.

The identification of the main stakeholders involved in the circular economy strategy (question 1.2) is fundamental, considering that the circular economy presupposes the integrated participation of multiple actors along the value chain.

In this sense, Company B presents an organizational structure in which the sustainability and circular economy department has a corporate-level role, operating across all of its 47 units. This department, led by a dedicated director, interacts with innovation, R&D, and production areas, while also maintaining direct communication with top management and the company's controlling family. Semiannual strategic planning meetings involving the executive board, owners, and key departments demonstrate the formal inclusion of internal stakeholders in defining short-, medium-, and long-term guidelines. This configuration aligns with the concepts of industrial symbiosis and intersectoral collaboration (Elia, Gnoni, and Tornese, 2017), which highlight the need for cooperation among different sectors and hierarchical levels to enable circular value chains.

Internal awareness (question 1.3) represents a decisive factor for the effective implementation of the circular economy, since, as highlighted by Khan and Haleem (2021), the transition from linear to circular models requires not only technological innovation but also cultural and behavioral transformations. In this context, it is observed that Company B has structured specific initiatives aimed at raising awareness among its employees and encouraging engagement in practices aligned with circularity.

Company B adopts a broader and more intensive approach, promoting recurring awareness campaigns (annual and monthly) aimed at both demystifying negative perceptions surrounding plastics and reinforcing the importance of proper disposal, selective collection, and reuse. This strategy is supported by constant visual and communication materials such as posters, informational calendars, and audiovisual content displayed in common areas, as well as external communication initiatives during industry events. This practice directly aligns with the concept of integrated communication for sustainability described by Vimal et al. (2022), who advocate the use of clear and accessible narratives to strengthen engagement among employees and society.

The dissemination of awareness among employees of partner companies (question 1.4) represents an essential component of the circular economy, since, as highlighted by Khan and Haleem (2021), the transition from linear to circular models requires not only technological advances but also cooperation among different sectors and cultural transformations that extend throughout the entire value chain.

Company B adopts a broader strategy based on institutional presentations, technical visits, and recurring awareness campaigns. Clients and partners who visit the company’s facilities are exposed to production processes and circularity practices. In addition, associated recyclers and internal facilities, such as the pyrolysis plant, participate in lectures and awareness programs, reinforcing the integration of direct partners into the circular ecosystem. The company also organizes periodic meetings and virtual activities with stakeholders in which topics related to sustainability and the circular economy are discussed. These practices are aligned with the concept of industrial symbiosis presented by Elia, Gnoni, and Tornese (2017), which highlights cooperation among companies as a strategy for closing material loops. Continuous communication through posters, calendars, and internal campaigns also reflects the concept of integrated communication for sustainability (Spreafico, 2022), which is essential for disseminating a circular culture.

The definition of well-established goals and objectives constitutes an essential factor for the consistent incorporation of the Circular Economy into organizational processes (question 1.5). As argued by Pauliuk (2018), progress toward circularity is not limited to the implementation of technical solutions but also requires the formalization of measurable strategic commitments capable of guiding investments, fostering innovation, and mobilizing stakeholders.

From this perspective, Company B indicates that it has structured objectives guiding its activities in packaging development, although these guidelines present specific approaches.

Thus, Company B presents an approach that, although less detailed, demonstrates a systematic commitment to incorporating circularity principles into R&D projects. According to the reports, every new development includes a sustainability-oriented alternative, even if it is not ultimately chosen by the client. This practice reveals the integration of circularity as a strategic guideline in innovation activities, reflecting what Hofstra and Huisingh (2014) describe as a gradual transition process, in which companies offer sustainable options to the market even when their adoption is limited by barriers, mainly costs and customer acceptance. In addition, the company reinforces the existence of internal indicators related to sustainability, quality, and cost, which demonstrates alignment with the need to monitor circular performance, pointed out by Pauliuk (2018) as essential for evaluating progress and feeding the decision-making process.

The implementation of the Circular Economy in companies in the packaging sector (question 1.6) involves challenges that go beyond strictly technical dimensions, also encompassing economic, cultural, and structural aspects. The literature shows that the transition from linear to circular models occurs gradually and in a complex manner, being permeated by obstacles such as high costs, technological limitations, lack of adequate infrastructure, and behavioral resistance (Jugend et al., 2020; Khan and Haleem, 2021; Loon, Diener, and Harris, 2021).

Company B presents a different perspective: although it states that it does not face major structural barriers, it acknowledges the existence of internal cultural resistance, especially among more experienced employees. The difficulty is related to the adoption of new production processes, such as replacing conventional structures with monomaterial alternatives. This type of barrier falls into the category of behavioral obstacles and organizational inertia, since changes in practices consolidated over time tend to be received with distrust or resistance (Khan and Haleem, 2021). The company reports that such resistance can be mitigated through clear explanations, quantitative data, and emphasis on environmental and commercial benefits, a practice that connects with the concept of internal engagement and awareness (Wang, Burke, and Zhang, 2022).

The selection of materials and components for packaging manufacturing (question 2.1) constitutes a central aspect for the effective implementation of the Circular Economy, as it directly influences the possibilities of reuse, recycling, and the environmental impacts throughout the product life cycle. As highlighted by Ofterdinger, Dlugoborskyte, and Herstatt (2021), choosing materials compatible with recycling processes is essential for enabling circularity, while Salvador et al. (2020) emphasize that decisions made during the design phase and in the selection of inputs determine the environmental performance of packaging in later stages.

Company B presents a more diversified portfolio, using a wide range of materials, including PET (Polyethylene Terephthalate), BOPP (Biaxially Oriented Polypropylene), PP (Polypropylene), PE (Polyethylene), and combinations of metallized and non-metallized films. In addition, the company also produces rigid packaging (injection-molded plastics) and uses recycled resins, including those derived from post-industrial waste. This model is compatible with the idea of flexibility in the selection of inputs depending on the type of application and the desired performance, but it faces challenges related to the availability volume of recycled resins and regulatory restrictions, especially those imposed by Anvisa, which limit the reuse of certain plastics in food and cosmetic packaging. Such barriers are consistent with the observations of Gagnon et al. (2022), who highlight legal and institutional obstacles as barriers to the expansion of circularity even when technically viable solutions exist.

Another relevant aspect in Company B is the mention of materials such as PVC (Polyvinyl Chloride), whose use in packaging is restricted not because of performance issues but due to concerns related to its production process and associated environmental risks. This example highlights the tension between technical feasibility and regulatory and social acceptability, a recurring dilemma in the literature on the transition toward the circular economy (Sumter et al., 2021).

Ensuring that the materials used in packaging production originate from renewable or sustainable sources represents one of the greatest challenges for the Circular Economy, especially in sectors highly dependent on fossil-derived materials, such as plastics (question 2.2). The literature indicates that the adoption of renewable raw materials requires not only technological innovation but also robust governance and traceability mechanisms, while also facing obstacles related to availability, costs, and regulatory requirements (Gagnon et al., 2022; Laurenti et al., 2015; Mohagheghian et al., 2021).

Company B adopts a more complex and multifaceted approach. The company acknowledges that 70% to 80% of resins still originate from fossil sources but highlights experiences with renewable inputs, such as green polyethylene from Braskem, derived from sugarcane. Despite its relevance, the use of this material is limited by high costs (up to 30% higher) and supply instability, since its production depends on the comparative profitability between ethanol and polyethylene. In addition, Company B highlights as a differentiating factor its internal control of two fronts: mechanical recycling, based on production scraps and waste from accredited cooperatives, and chemical recycling, which allows plastic waste to be transformed into pyrolysis oil and subsequently converted into resins. These initiatives are aligned with the notion of closing material loops advocated by Sandoval, Jaca, and Ormazabal (2018) and with the strategy of cyclical eco-innovation, which seeks to reduce dependence on virgin sources by reinserting waste as inputs in production (Hofstra and Huisingh, 2014).

The adoption of Circular Economy practices in packaging development provides benefits that extend across multiple dimensions: environmental, economic, social, and organizational (question 2.3). As indicated in the literature, the incorporation of circularity principles contributes to reducing environmental impacts, extending product life cycles, preserving material value, and creating new business opportunities (Batwara et al., 2022; Evrard et al., 2021; Gagnon et al., 2022; Jugend et al., 2020).

Company B adopts a more environmental and social perspective when addressing the benefits of the Circular Economy. For the company, the main contribution lies in removing plastics from the environment, reducing the improper disposal of waste in dumps and landfills, and decreasing dependence on fossil resources. In addition, the company emphasizes that these practices should also be understood from an intergenerational perspective, as they preserve available resources for future generations and prevent scenarios of environmental depletion. This perspective is directly aligned with the literature on sustainable development, which advocates balancing current consumption with the planet's regenerative capacity (Ellen MacArthur Foundation, 2019).

The literature on the Circular Economy shows that the costs associated with its implementation (question 2.4) are diverse and go beyond the initial investment in equipment. They include expenses related to machinery and infrastructure, additional operational costs such as energy, maintenance, and recycled inputs, transaction costs including certifications, audits, and contracts with suppliers and recyclers, adaptation and quality costs related to process control and product validation to maintain performance, as well as organizational costs (Gagnon et al., 2022).

Company B describes a different cost structure: the main pressure lies in the price of raw materials (virgin resins versus green or recycled resins) and in the commercial costs associated with transferring this price difference to customers. From a production standpoint, some substitutions (for example, changing from PET/PE structures to PE/PE monomaterial structures) do not substantially alter the process, meaning the incremental investment may be low; however, the cost per kilogram of renewable or recycled resin is significantly higher. Additionally, supply volatility (for example, bio-based resins linked to ethanol production) introduces risks related to availability and pricing. The company also highlights intangible costs, such as efforts to convince customers, operator training, and temporary efficiency losses during the transition. Importantly, Company B's position is that in a large-scale transition these costs would likely be diluted and could even generate economic gains through economies of scale and process standardization, although such a scenario requires time and market coordination.

The literature on the Circular Economy and environmental sustainability indicates that organizations seek to reduce impacts in three main areas: solid waste, through recycling and material recovery in order to avoid improper disposal; the use of natural resources, emphasizing water and energy efficiency; and carbon emissions related to production, transportation, and disposal (Brazil, 2010; Brazil, 2022). Incorporating these aspects into packaging production processes is particularly relevant due to the sector's heavy dependence on fossil-based plastics and the large volume of waste generated, making it important to analyze environmental impacts and the strategies adopted by companies to minimize them (question 2.5).

In this context, Company B presents a more comprehensive and structured approach linked to a corporate sustainability department. The company reports having life cycle assessment (LCA) programs for different products, monitoring reductions in carbon emissions, including projects that generate negative emission balances in certain product lines. In addition, the company highlights the use of renewable energy (64% of total consumption, from solar and wind sources) and the establishment of long-term environmental targets (2040–2050), aligned with international decarbonization commitments.

The verification of partnerships with companies and suppliers is an important aspect of the Circular Economy (question 2.6). The literature emphasizes that successful implementation of the Circular Economy depends strongly on interorganizational collaboration, as no company can independently close material loops and promote a truly sustainable supply chain. Partnerships with recyclers, suppliers of sustainable raw materials, cooperatives, and regulatory bodies are considered essential mechanisms for enabling the flow of secondary materials and legitimizing environmental practices in the market and society (Elia, Gnoni, and Tornese, 2017; Ellen MacArthur Foundation, 2019; Khan and Haleem, 2021; Wang, Burke, and Zhang, 2022).

Company B presents a more diversified and structured partnership network. The company holds the ISCC Plus certification, internationally recognized as a sustainability and traceability standard, and is also in the process of obtaining other relevant certifications to serve both national and international clients. The company also maintains contracts with cooperatives, such as the one located in Pindamonhangaba, which play a key role in supplying its pyrolysis plant that converts plastic waste into reusable chemical inputs. In addition, the company relies both on internal supply of recycled materials and on the acquisition of sustainable inputs from the market, such as green PET. This set of partnerships demonstrates an integrated approach that connects local actors (cooperatives), internal infrastructure (pyrolysis and mechanical recycling), and global commitments (international certifications).

Extending the useful life of packaging (question 3.1) is one of the central principles of the Circular Economy, as it helps reduce the demand for virgin raw materials, minimize waste generation, and optimize the use of natural resources. The literature indicates that this strategy can be implemented through different mechanisms, including intelligent design such as modularity and ease of disassembly, durable materials that ensure resistance and protection of contents, consumer reuse, and post-use value recovery through recycling or energy recovery (Amend et al., 2022; Asif et al., 2021; Bressanelli et al., 2020; Joustra, Flipsen, and Balkenende, 2021).

Company B describes a broader set of practices and conditions. First, the company indicates that many aspects related to extending product life arise from the production process itself, such as increased durability resulting from lamination or coextrusion, which extends the shelf life of films and plastic containers. In addition, the company emphasizes the relevance of consumer-oriented design, such as the use of zippers in flexible packaging, transparent windows, and removable labels, which facilitate household reuse. The company also highlights the growing influence of market pressure and consumer awareness, which drive packaging redesign even when this implies higher production costs. Thus, Company B associates life extension with a design strategy and social acceptance aligned with "design for reuse" practices described in the literature.

The adoption of Circular Economy practices in the packaging sector depends essentially on the development of concrete solutions that demonstrate how theoretical principles are translated into real products (question 3.2). The literature highlights that the effective application of circularity occurs through recycling or reuse, reducing dependence on virgin raw materials and mitigating environmental impacts (Ellen MacArthur Foundation, 2019; Genovese et al., 2015). In this context, practical examples of circular packaging become essential not only for alignment with environmental goals but also for strengthening corporate credibility in the market and among consumers.

Company B presents examples that also reflect the advancement of the Circular Economy at an industrial scale. Among these are biscuit packaging solutions produced from materials collected through the company's own selective collection points, which are transformed into recycled resins and reintroduced into the market.

Another example is bottle labels produced with PCR (post-consumer recycled plastic), containing up to 50% recycled material. Although they cannot be applied directly to food or beverage packaging due to regulatory restrictions, their use in secondary packaging already represents a significant advance.

The company also highlights an ongoing project involving recycled bottles, which are already available in the market and represent the potential for circularity in products with large-scale production and high market visibility.

The use of structured methodologies such as Circular Function Deployment (CFD) can be a crucial element for systematically incorporating Circular Economy principles into packaging development (question 3.3). Inspired by Quality Function Deployment (QFD), this tool aims to integrate circularity criteria into the early phases of product design, promoting stronger alignment between innovation, sustainability, and market demands (Vimal et al., 2022).

Company B indicates a more open position toward the methodology, although in an indirect or unstructured manner. While there is no clear evidence of formal CFD implementation, elements described by the company suggest that similar practices already exist within areas such as R&D, innovation, and sustainability. The report also suggests a level of familiarity with the concepts associated with the model, even if they are embedded within other management tools. In this sense, the company recognizes the potential of the methodology but still needs to consolidate its application in a more explicit and integrated manner.

Regulatory compliance plays a strategic role in the implementation of the Circular Economy in packaging, as it defines both the limits and opportunities for innovation. The plastics and packaging sector, in particular, is subject to a set of regulations involving environmental policy, public health, and market governance, reflecting growing global concern about waste management, recycling, and pollution reduction (question 4.1).

In the case of Company B, there is broader attention to the regulatory landscape, including national legislation and international agreements. In addition to the National Solid Waste Policy (PNRS), the company also references Extended Producer Responsibility (EPR) and the Recycling Incentive Law (LIR) as instruments shaping circularity practices, particularly with regard to reverse logistics. The company also highlights the Global Treaty to Combat Plastic Pollution, which introduces international-scale commitments. Importantly, the company closely monitors emerging regulations such as the Plastic Decree and Bill 2524, which may directly impact production by restricting certain materials or requiring the use of recycled content. In this case, a forward-looking regulatory perspective can be observed, indicating greater strategic maturity.

The issue regarding demand for sustainable packaging from customers reveals different perceptions between the two companies analyzed (question 4.2). Company B stated that customers do not directly require it but frequently request alternatives, especially those without aluminum, although not all projects proceed to approval.

This reality aligns with the literature, which identifies barriers on both the demand and supply sides. Zikopoulos (2022) notes that environmental awareness among consumers is still insufficient to sustain effective market transformation, explaining why, even when interest exists, the willingness to pay additional costs remains limited.

Demand for sustainable packaging (question 4.3) may manifest in various ways and reflects the increasing pressure exerted by both customers and society on companies.

At Company B, requests occur primarily through strategic directives coming from the headquarters or top management of client companies, which determine the need to develop sustainable packaging for specific product lines. This top-down approach demonstrates that, in many cases, the decision to adopt circular packaging does not originate solely from operational departments but is linked to corporate governance and global commitments. This confirms that international pressures often play a stronger role in accelerating the Circular Economy in emerging economies (Loiseau et al., 2016; Sandoval, Jaca, and Ormazabal, 2018).

This situation aligns with the theoretical framework, which indicates that the Circular Economy is influenced by pressures at different levels: micro (companies and consumers), meso (value chains and recycling networks), and macro (public policies and regulations), all acting as drivers of circular practices (Sandoval, Jaca, and Ormazabal, 2018). In this context, customer demand may manifest either through formal requirements, such as contracts and certifications, or through informal pressures, including consumption trends and the pursuit of a positive environmental image.

In addition, customers' perception of value regarding sustainable packaging also influences the process. Pretner et al. (2021) emphasize that although some consumers attribute positive value to circular products, many still associate recycled packaging with lower quality, which creates resistance when approving or adopting alternatives proposed by suppliers. Company B observes that many projects do not even reach the approval stage.

The implementation of Circular Economy practices in packaging development faces different obstacles (question 4.4), which depend on each organization's trajectory and its level of maturity regarding sustainability.

Company B does not identify significant obstacles in its trajectory, since it was originally established as a recycling company and has incorporated circularity logic into its culture and production processes from the beginning.

For the company, practices such as reverse logistics, recycling, and environmental awareness are part of its organizational DNA, so changes in terminology (such as the introduction of the term "circular economy") are perceived more as a semantic evolution than as operational disruptions.

In this sense, Company B considers that the challenges were internalized from its foundation and have been minimized through the integration between organizational culture and sustainability practices.

Addressing challenges (question 4.5) in implementing the Circular Economy in the packaging sector depends on strategic, economic, and cultural aspects, which manifest differently in each company according to its trajectory and organizational context.

In the case of Company B, internal challenges have not been significant because circularity has been part of its business model since its origin. However, the company recognizes that the main difficulty lies in convincing customers, as price often remains the predominant criterion in packaging purchasing decisions. In this sense, the challenge is not only developing circular solutions internally but also overcoming external barriers related to value perception and the market's willingness to pay for sustainable products.

These experiences are consistent with the literature presented in the theoretical framework (Section 2 of this thesis), which emphasizes that overcoming these challenges requires not only investments but also stakeholder engagement strategies and the use of tools such as Life Cycle Assessment (LCA), which provide technical data to demonstrate environmental benefits and add value to sustainable solutions (Ghisellini, Cialani, and Ulgiati, 2016).

The management of packaging life cycles by companies (question 5.1) reveals different levels of maturity regarding the adoption of the Circular Economy.

Company B demonstrates an advanced level of activity, with dedicated personnel in the sustainability area and initiatives that cover the entire circular plastic economy cycle. The company adopts practices ranging from packaging redesign for improved recyclability to mechanical and advanced recycling, reinserting recycled resin into new products. In addition, the company stands out as one of the main recyclers in Latin America, assuming an active role in reverse logistics and demonstrating how circularity can be operationalized in a systemic and integrated manner.

Monitoring customer perceptions regarding the Circular Economy (question 5.2) continues to be a sensitive aspect within the observed business practices.

Company B does not conduct any type of monitoring related to how customers deal with the Circular Economy. Although the company has more consolidated practices in other areas, such as reverse logistics and mechanical recycling, the absence of monitoring regarding consumer behavior reinforces a common challenge among organizations: the difficulty of integrating the end user as an active agent in closing material loops.

This aspect is consistent with the theoretical framework, which highlights that the Circular Economy cannot be restricted to companies but must involve the entire value chain, including consumers, recycling cooperatives, and regulatory agencies. Dantas et al. (2021) point out that one of the major obstacles to the effectiveness of the circular model is precisely the lack of systematic monitoring of product use and disposal, which creates gaps in the reuse cycle.

Consumer engagement throughout the packaging life cycle (question 5.3) is an essential element for the effectiveness of the Circular Economy, since the active participation of customers contributes to closing reuse cycles and reducing environmental impacts.

Company B presents a more advanced scenario, although still under development. The company is structuring a pilot project in partnership with a large client and a cooperative. In this model, post-consumer packaging produced by Company B is collected and processed by another company within the group (through washing, de-inking, and delamination stages) and transformed into PCR (post-consumer recycled) resin. This resin is then reinserted into the production chain to manufacture secondary packaging for the same client. Although the project is still in the testing phase, it already demonstrates positive results and significant potential for expansion, revealing a clear circularity strategy applied to the end customer. This practice is aligned with the concept of industrial symbiosis and network collaboration (Sandoval, Jaca, and Ormazabal, 2018).

Collecting customer feedback (question 5.4) is a fundamental component for aligning business practices with the principles of the Circular Economy, as it enables companies to understand expectations, identify barriers, and guide improvements in products and processes.

Company B does not have a specific feedback collection system focused exclusively on the Circular Economy. Monitoring occurs indirectly through annual customer satisfaction surveys. These surveys include questions about sustainable proposals, but in a relatively superficial manner. Although there is a protocol for contacting customers in the case of detractor responses, the company reports that no such situations have occurred so far.

This practice contrasts with the recommendations of Genovese et al. (2015) and Wang, Burke, and Zhang (2022), who emphasize that feedback and traceability mechanisms are essential for companies to redesign their strategies, identify bottlenecks, and promote circularity at a systemic level.

The benefits perceived by customers (question 5.5) when choosing sustainable packaging are mainly associated with strengthening brand image and environmental recognition among consumers and society. This result is consistent with the literature, which indicates that circular products can generate intrinsic value by reducing the amount of waste sent to landfills and by meeting the environmental values and beliefs of some consumers (Evrard et al., 2021; Pretner et al., 2021).

In the case of Company B, the perception of benefits occurs indirectly, since the company does not sell directly to final consumers. In this context, the most evident returns come through industry awards and repeat orders of packaging, signaling recognition by the market and corporate clients but without a clear systematization of how end consumers perceive the advantages of circular solutions. This suggests that the company still has room to expand its activities in measuring and communicating the benefits related to the circularity of its packaging.

Evaluating and monitoring the results of Circular Economy initiatives (question 5.6) are fundamental to understanding the effectiveness of these practices and supporting strategic adjustments when necessary.

Company B presents a formalized and quantitative approach, using specific indicators such as reductions in the use of virgin raw materials, increases in recycled content in its products, the volume of materials recycled in its own facilities, and reductions in associated emissions. This practice reflects a stronger alignment with performance management principles, allowing circularity outcomes to be monitored and communicated objectively.

The literature emphasizes the importance of measurement within the Circular Economy, highlighting that only well-defined indicators allow concrete evaluation of environmental, economic, and social benefits (Pauliuk, 2018).

Monitoring the progress of Circular Economy initiatives (question 5.7) depends on adopting indicators capable of quantifying the results achieved by companies. Among the main parameters used are the amount of recycled plastic, the proportion of recycled material incorporated into packaging, the reduction of carbon intensity per ton produced, and the reduction in the use of virgin raw materials. These metrics reflect recommendations from the literature, which emphasizes the need for indicators capable of measuring circularity, material flows, product durability, and economic value generated throughout the life cycle (Niero and Kalbar, 2019; Figge et al., 2018).

Company B adopts more specific and quantitative metrics, such as tons of plastic recycled per year, the percentage of recycled content present in its packaging, reductions in carbon intensity per ton produced, and the volume of virgin raw material avoided. This set of indicators allows the company not only to measure internal results but also to generate comparable reports aligned with international sustainability standards, strengthening its credibility with clients and regulatory bodies.

5.3 Cross-case Analysis

After analyzing each case separately (Company A presented in Section 5.2.1 and Company B presented in Section 5.2.2), it is important to conduct a comparative analysis between the two cases, which is the objective of this section.

When analyzing the situation of the companies regarding the implementation of the Circular Economy, it can be stated that Company A and Company B incorporate Circular Economy principles through distinct and complementary strategies. The former adopts a proactive approach focused on investments in technology, innovation, and the development of circular products, aiming to anticipate trends and assume a leadership position in the sector. In contrast, the latter builds its trajectory based on mechanical recycling and the reverse logistics of PET bottles, later advancing toward chemical recycling as a means of closing material loops. While Company A emphasizes value creation through innovation and strategic positioning, Company B demonstrates an operational evolution oriented toward the continuous reinsertion of materials into the production system.

The practices described are supported by the literature as they relate to cyclical and regenerative eco-innovations, as discussed by Sandoval, Jaca, and Ormazabal (2018) and Hofstra and Huisingh (2014), as well as to the concept of a restorative and regenerative model that maintains products and materials at their highest level of utility and value, according to the Ellen MacArthur Foundation (2019). They also connect with the centrality of the 3Rs proposed by Ghisellini, Cialani, and Ulgiati (2016), with the definition of reverse logistics as an essential instrument for reinserting materials into the production cycle (Genovese et al., 2017; Wang, Burke, and Zhang, 2022), and with the discussion on closing material loops presented by Korhonen et al. (2018). These theoretical foundations justify the analyzed practices by demonstrating that they align with the structural principles of the Circular Economy.

Thus, it can be concluded that despite strategic and operational differences, both companies demonstrate consistent adherence to the foundations of the Circular Economy, showing that multiple trajectories can converge toward the transition from a linear to a circular model of production and consumption.

When analyzing long-term visions related to the Circular Economy, it can be observed that Company A and Company B adopt different strategic directions, although both converge toward the expansion of circularity. Company A structures its future projection around the expansion of recycled and renewable raw materials, investments in advanced technologies, and the development of products aligned with this model, also incorporating reverse logistics programs and environmental certifications as instruments for consolidating leadership. In contrast, Company B bases its planning on defined temporal milestones, emphasizing sustainability integrated into organizational strategy and prioritizing renewable energy, the substitution of fossil inputs, and the continuous improvement of production practices. While the first prioritizes differentiation through innovation and strategic positioning, the second guides its actions through a progressive transition supported by long-term goals.

These guidelines are supported by the theoretical foundations of the Circular Economy, as they relate to the elimination of waste and pollution, the maintenance of materials in use, and the regeneration of natural systems proposed by the Ellen MacArthur Foundation (2019). They are also connected with the relevance of reverse logistics for closing material loops (Genovese et al., 2017), the concept of regenerative eco-innovation aimed at generating long-term value (Hofstra and Huisingh, 2014), the defense of transitioning to renewable energy as a key element of circularity (Ghisellini, Cialani, and Ulgiati, 2016), and the need to adapt business models to sustain circular practices (Elia, Gnoni, and Tornese, 2017). In this way, the strategies described maintain a direct relationship with the conceptual assumptions that structure the transition toward more sustainable production systems.

Therefore, it can be concluded that although guided by different strategic approaches, both companies demonstrate consistent alignment with Circular Economy principles, indicating that different trajectories can support the consolidation of circular practices in the long term.

The analysis of practices aimed at promoting the Circular Economy in packaging development reveals distinct strategic approaches between Company A and Company B. Company A adopts a structured and proactive model, evidenced by the development of 100% recyclable packaging, the incorporation of recycled resins, the reduction of material thickness, and significant investments in machinery and partnerships within the production chain. These actions indicate integration between design, technological innovation, and stakeholder engagement. In contrast, Company B presents an approach conditioned by market dynamics, offering more sustainable alternatives such as monomaterial and certified packaging while acknowledging limitations related to cost and customer adoption. While the first consolidates a strategy oriented toward structural transformation of the production model, the second operates through gradual adaptation to economic conditions and market demand.

The strategies described maintain a direct relationship with design for circularity proposed by the Ellen MacArthur Foundation (2019), with the application of the 3Rs presented by Ghisellini, Cialani, and Ulgiati (2016), and with the concept of resource efficiency discussed by Wu et al. (2014). They are also linked to the perspective of cyclical and regenerative eco-innovations aimed at closing material loops (Sandoval, Jaca, and Ormazabal, 2018), to the understanding of systemic innovation and value chain engagement highlighted by Heyes et al. (2018) and Rajput and Singh (2019), to the economic and structural barriers identified by Ghisellini, Cialani, and Ulgiati (2016), and to the concept of gradual transition toward circularity described by Dantas et al. (2021). These references theoretically support the observed practices, demonstrating their alignment with the assumptions of the Circular Economy.

Given this scenario, it can be observed that both companies demonstrate alignment with Circular Economy principles in packaging development, although through different strategic trajectories, highlighting the multiplicity of possible paths for incorporating circular principles in the business context.

Table 9 presents a comparison between Companies A and B and their relationship with the theory regarding strategies or Circular Economy practices used in the packaging development process.

Dimension	Company A	Company B	Relationship with the Theory
Product Innovation	Launch of Ecoprime, a 100% recyclable and shrinkable packaging.	Development of more sustainable structures (e.g., monomaterials) for clients.	Ellen MacArthur Foundation (2019): design and development as key drivers of circularity.
Materials	Use of certified recycled resins; reduction of film thickness.	Offering structures that facilitate recycling, although cost limits adoption.	Ghisellini, Cialani, and Ulgiati (2016): reduction of raw material consumption as a core principle of the Circular Economy.
Processes	Investment of R$30 million in machinery for recycling and material reuse.	Production adjusted to client demands, still limited by costs.	Vimal et al. (2022): need for technological innovation to enable the Circular Economy.
Stakeholders	Partnerships with suppliers, recyclers, and certification bodies; internal engagement.	Proposals for more sustainable packaging presented directly to clients.	Genovese et al. (2015): interorganizational collaboration as a pillar of circularity.

Table 11: Circular economy strategies or practices in packaging development
Source: Prepared by the author

The analysis of the stakeholders involved in the Circular Economy strategy reveals distinct organizational configurations between Company A and Company B. Company A structures its activities through the articulation between internal actors, such as the board of directors and technical departments, and a diversified network of external agents, including certified suppliers, recyclers, cooperatives, laboratories, environmental certification bodies, and clients, all of whom directly influence the development of sustainable solutions. In contrast, Company B concentrates its strategy within a formalized corporate governance structure, in which the sustainability department has a transversal role and interacts with innovation, R&D, production, and top management, while also involving the controlling family in periodic decision-making processes. While the former emphasizes integration along the value chain with strong participation of external partners, the latter highlights internal coordination and strategic alignment across multiple operational units.

The importance attributed to these different actors is related to the understanding that the Circular Economy depends on articulation between micro, meso, and macro levels to enable circular flows of materials, energy, and information, as discussed by Sandoval, Jaca, and Ormazabal (2018). It is also connected to the systemic approach to circularity described by the Ellen MacArthur Foundation (2019), which emphasizes collaboration among companies, suppliers, customers, and certification organizations in order to preserve the value of resources, as well as to the concepts of industrial symbiosis and intersectoral collaboration presented by Elia, Gnoni, and Tornese (2017), which highlight cooperation between sectors and hierarchical levels in consolidating circular value chains. These theoretical foundations support the central role of stakeholders as a structuring element of the analyzed strategies.

Therefore, it can be observed that both companies demonstrate alignment with the principles of the Circular Economy by recognizing the importance of multisectoral cooperation and organizational integration, although they adopt different institutional arrangements to operationalize this guideline.

Table 10 presents a comparison of three types of stakeholders between Companies A and B and their relationship with the theory.

Category	Company A	Company B	Relationship with the Theory
Internal	Board of Directors; R&D; Engineering; Quality; Marketing.	Corporate sustainability department; R&D (innovation and daily operations); production.	Elia, Gnoni, and Tornese (2017): internal stakeholders as key decision-makers.
External	Certified suppliers; recyclers; cooperatives; certification bodies; clients.	Clients (strategic partners); recycling companies (DEC, pyrolysis); family board.	Sandoval, Jaca, and Ormazabal (2018): importance of multiple actors to enable circularity.
Government	Strategic planning aligned with sustainability trends.	Semiannual meetings between the board of directors, sustainability, and innovation departments.	Wang, Burke, and Zhang (2022): governments can create laws, provide incentives, and ensure infrastructure to support circular design and recycling.

Table 12: Key stakeholders in the circular economy strategy
Source: Prepared by the author

The analysis of internal awareness practices reveals distinct approaches between Company A and Company B in promoting the Circular Economy among their employees. Company A adopts a structured model based on periodic training programs that address conceptual foundations, sector innovations, and strategic guidelines, integrating these contents into the routines of production and development departments. This dynamic facilitates the technical incorporation of circularity into operations. In contrast, Company B implements recurring campaigns focused on cultural awareness, emphasizing proper disposal, selective collection, and reuse, supported by visual materials and internal and external communication actions. While the former prioritizes formal training oriented toward organizational practice, the latter invests in continuous communication aimed at transforming perceptions and behaviors.

The initiatives described are related to the understanding that the transition to the Circular Economy requires cultural and behavioral changes in addition to technological advances, as highlighted by Khan and Haleem (2021). They are also associated with the concept of corporate education and internal stakeholder engagement presented by Dokter, Thuvander, and Rahe (2021), the perspective of integrated communication for sustainability proposed by Vimal et al. (2022), and the emphasis on training and collective involvement discussed by Jönbrink (2020) and Spreafico (2022). These theoretical references support the strategies adopted by demonstrating that the consolidation of circular practices depends on the dissemination of knowledge and organizational mobilization.

Thus, both companies demonstrate alignment with the principles of the Circular Economy by recognizing internal awareness as a strategic element for sustaining organizational transformation and strengthening a culture oriented toward circularity.

The analysis of awareness strategies among partners highlights differentiated approaches between Company A and Company B in promoting the Circular Economy. Company A adopts a more personalized practice based on technical dialogue during negotiations and joint projects, guiding partners regarding certifications, market requirements, and trends, thereby reinforcing the operationalization of circular solutions. In contrast, Company B prioritizes a broader and more institutional approach, using presentations, technical visits, lectures, awareness programs, and internal campaigns aimed at integrating clients and recyclers into the circular ecosystem. While the former seeks deep and technical engagement, the latter emphasizes cultural dissemination and continuous communication of Circular Economy values and practices.

The practices adopted reflect theoretical concepts emphasizing the need for multisectoral articulation to enable circular flows of materials, energy, and information, as discussed by Khan and Haleem (2021) and Sandoval, Jaca, and Ormazabal (2018). They are also related to capacity building and knowledge dissemination as tools for implementing circularity (Wang, Burke, and Zhang, 2022), the importance of creating reliable markets for recycled materials (Genovese et al., 2017), industrial symbiosis and cooperation among companies (Elia, Gnoni, and Tornese, 2017), and integrated communication for sustainability (Spreafico, 2022). Economic and scale-related challenges that limit the full adoption of circular practices are aligned with the barriers identified by Diaz, Reyes, and Baumgartner (2022), while the construction of collaborative ecosystems is emphasized by Bocken, Schuit, and Kraaijenhagen (2018).

Therefore, both companies demonstrate that partner awareness is a strategic driver for implementing the Circular Economy, showing that different trajectories can strengthen the construction of circular ecosystems and the integration of sustainable practices along the value chain.

The analysis of goals and objectives related to the integration of Circular Economy principles reveals complementary approaches between Company A and Company B. Company A establishes explicit and quantitative targets aimed at increasing the use of recycled raw materials, developing 100% recyclable packaging, optimizing processes, and obtaining environmental certifications, with a focus on technological innovation and encouraging partners and clients to adopt sustainable practices. In contrast, Company B adopts a strategy based on the continuous offering of sustainable alternatives in packaging development, even when these options are not chosen by clients, integrating circularity into the R&D process and using internal indicators related to sustainability, quality, and cost. While the former prioritizes the formal definition of objectives and measurement of results, the latter emphasizes the transversal incorporation of circularity into innovation activities.

These practices are supported by the literature, which highlights the need for measurable strategic targets to guide investments and stakeholder engagement

(Pauliuk, 2018), the centrality of the 3Rs as a structuring principle (Ghisellini, Cialani, and Ulgiati, 2016), and regenerative eco-innovation as a means of creating additional value (Hofstra and Huisingh, 2014). Institutional credibility to foster markets for recycled inputs is emphasized by Khan and Yu (2021), while the gradual process of offering sustainable alternatives—even when limited by market barriers—is described by Hofstra and Huisingh (2014). Furthermore, Linder, Sarasini, and Van Loon (2017) emphasize that clear indicators enable monitoring and feedback of circular performance. These theoretical foundations justify the practices adopted by demonstrating that defining goals and integrating circularity into innovation processes are consistent with Circular Economy principles.

Thus, although they differ in terms of level of detail and operationalization, both companies implement strategies that strengthen circularity in packaging, demonstrating that different pathways can support the transition from a linear to a circular model within the industrial sector.

Table 11 presents the goals of Companies A and B separated by dimensions and establishes their relationship with the theory.

Dimension	Company A	Company B	Relationship with the Theory
Environmental	Increase the use of recycled raw materials; reduce plastic consumption.	Always offer sustainable alternatives to clients, even if they are not adopted.	Salvador et al. (2020): circularity as the reduction of waste and fossil-based inputs.
Economic	Expand recyclable product lines such as Ecoprime; make processes more efficient.	Goals associated with cost, sustainability, and quality, adjusted according to market feasibility.	Loiseau et al. (2016): sustainability linked to market efficiency.
Organizational	Seek certifications and comply with environmental standards	Goals shared across all R&D areas and aligned with the corporate sustainability department.	Ko (2020): integration of the Circular Economy into corporate strategy.
Social	Raise awareness among clients and partners regarding the use of sustainable packaging.	Communicate objectives to the market and align goals with stakeholder demands.	Figge et al. (2018): engagement of external stakeholders as a driver of circularity.

Table 13: Goals and objectives in the integration of the circular economy
Source: Prepared by the author

The analysis of the barriers faced in implementing the Circular Economy reveals significant differences between Company A and Company B. Company A identifies the main obstacles as the high costs of investments in equipment, product development, and the acquisition of certified recycled raw materials, as well as technical challenges in adapting industrial processes and difficulties in ensuring the quality of circular packaging. The company also observes limitations in the national supply of materials and initial resistance from customers due to the additional cost of sustainable packaging. In contrast, Company B reports barriers of a cultural and organizational nature, particularly internal resistance from more experienced employees regarding the adoption of new production processes and the replacement of conventional materials with monomaterial alternatives. These challenges are mitigated through clear communication and emphasis on environmental and commercial benefits. Thus, while one company primarily faces economic and technical barriers, the other deals mainly with behavioral and change management challenges.

The difficulties reported are supported by the literature, which highlights the complexity of transitioning to circular models and the different types of barriers that may arise. Economic barriers and competitiveness issues between virgin and recycled inputs are identified by Gagnon et al. (2022), while the need for advances in eco-innovation to overcome technical limitations is discussed by Hofstra and Huisingh (2014). Behavioral and cultural resistance is emphasized by Khan and Haleem (2021), and the importance of articulating the entire value chain to enable circularity is highlighted by Wang, Burke, and Zhang (2022). These references justify the observed practices, demonstrating that the challenges faced by the companies are directly related to the economic, technical, and cultural factors discussed in the theoretical framework.

The analysis shows that, although different in nature and magnitude, the barriers faced reflect the structural complexity of the Circular Economy in the packaging sector. The adoption of integrated strategies involving technological innovation, value chain engagement, and awareness programs is essential to overcome these obstacles and advance the transition toward more circular production and consumption models.

Table 12 presents a comparison of the barriers identified by Companies A and B and their relationship with the theory.

Type of barrier	Company A	Company B	Relationship with the Theory
Economic	High cost of machinery, recycled inputs, and development of new products.	Cost of differentiated structures and the need to explain and justify changes.	Gagnon et al. (2022): cost as a central barrier to circularity.
Technical	Adaptation of industrial processes and quality assurance.	Resistance from operators to new production processes (e.g., monomaterials).	Joustra et al. (2022): technical and know-how challenges in the circular transition.
Market/ Customers	Customer resistance to adopting sustainable packaging due to the additional cost.	Customers may accept only when they understand the added value.	Cordella et al. (2021): the market is still not fully prepared for the costs of circularity.
Suppliers	Scarcity of national suppliers prepared to meet Circular Economy demands.	Lower relevance, as part of the recycling process is controlled internally.	Wang, Burke, and Zhang (2022): importance of infrastructure to ensure circularity.

Table 14: Barriers in the implementation of the circular economy
Source: Prepared by the author

The comparative analysis shows that Company A adopts a restrictive and selective strategy in the choice of materials, prioritizing polyolefin resins such as polyethylene (PE) and polypropylene (PP) due to their high recyclability and applicability in flexible packaging, as well as high-molar-mass polymers that facilitate recycling and increase the efficiency of material recovery. In contrast, Company B adopts a broader approach, using a variety of materials, including PET, BOPP, PP, PE, combinations of metallized and non-metallized films, as well as recycled resins and rigid plastics. While Company A focuses on maximizing recyclability and packaging functionality, Company B seeks flexibility to serve different markets, facing regulatory challenges and limitations related to the availability of recycled inputs.

The material choices are theoretically supported as they relate to enabling circularity and improving the environmental performance of the product life cycle. The selection of materials compatible with recycling is highlighted as a key factor for circularity by Ofterdinger, Dlugoborskyte, and Herstatt (2021), while the importance of design and input decisions for subsequent environmental performance is emphasized by Salvador et al. (2020). The prioritization of recyclable polymers and design for circularity are aligned with the guidelines of the Ellen MacArthur Foundation (2019), and the development of solutions that reconcile functionality and recyclability connects with the concept of regenerative eco-innovation described by Hofstra and Huisingh (2014). The literature also recognizes legal and institutional barriers to expanding circularity (Gagnon et al., 2022) and regulatory and environmental dilemmas associated with the use of certain materials (Sumter et al., 2021), which helps explain the strategic decisions observed in the companies.

It can be observed that both companies translate Circular Economy principles into concrete material choices, each adapting its strategy to market demands, regulatory requirements, and technical feasibility. The careful management of inputs demonstrates that the development of circular packaging requires balancing recyclability, performance, and compliance, making these decisions central to the effectiveness of the transition toward more circular production models.

Table 13 presents comparative characteristics of material usage between Companies A and B and their relationship with the theory.

Category	Company A	Company B	Relationship with the Theory
Main plastics	PE and PP.	PET, BOPP, PP and PE.	Spreafico (2022): selection of materials focused on recyclability.
Properties	High-molar-mass polymers to facilitate recycling.	Different structures (metallized, transparent, matte), depending on application and barrier function.	Ellen MacArthur Foundation (2019): design for recycling and functionality.
Recycled materials	Use of recycled resins, still in a limited way.	Post-industrial recycled resins and materials from cooperatives; regulatory restrictions (e.g., Anvisa).	Gagnon et al. (2022): regulatory and technological barriers limit circularity.
Restricted materials	Not mentioned.	PVC is not used in packaging due to legal and environmental restrictions, although it is applied in other sectors (e.g., pipes).	-

Table 15: Types of materials and components used
Source: Prepared by the author

The comparative analysis shows that Company A adopts a strategy focused on supply chain control, careful supplier selection, and the request for proof of origin to ensure the use of renewable or recycled materials, while facing limitations related to availability and traceability in the market. In contrast, Company B prioritizes operational autonomy through the implementation of mechanical and chemical recycling, as well as experiments with renewable inputs such as green polyethylene, partially overcoming supply constraints but dealing with challenges related to cost, scale, and regulation. While Company A emphasizes reliability and governance, Company B invests in its own infrastructure and emerging technologies to reduce dependence on virgin raw materials.

The observed practices are theoretically supported as they relate to governance mechanisms, traceability, and eco-innovation. The literature highlights the importance of technological innovation and supply chain control to ensure credibility in the use of circular materials (Gagnon et al., 2022; Laurenti et al., 2015; Mohagheghian et al., 2021). The application of transparency and traceability criteria is consistent with Dumée (2022) and Khan et al. (2021), while the closing of material loops and cyclical eco-innovation—aimed at reducing dependence on virgin inputs by reinserting waste into production processes—are discussed by Sandoval, Jaca, and Ormazabal (2018) and Hofstra and Huisingh (2014). These theoretical foundations justify the strategies adopted, demonstrating alignment with the structural principles of the Circular Economy.

It can be observed that, despite adopting different approaches, both companies advance in the integration of renewable and recycled materials in ways that strengthen circularity, balancing input availability, governance mechanisms, and technological innovation. This combination of efforts demonstrates that multiple trajectories can contribute to reducing dependence on virgin resources and strengthening the Circular Economy in the packaging sector.

Table 14 presents a comparison between Companies A and B and their relationship with the theory regarding how they ensure that the origin of the materials used comes from renewable sources.

Estrategy	Company A	Company B	Relationship with the Theory
Traceability	Selection of suppliers that declare sustainable practices; request for supporting documentation.	Partial use of green PE from Braskem (sugarcane), limited by cost and unstable supply.	Jugend et al. (2020): traceability as a key element of circularity.
Mechanical recycling	Still limited use, dependent on external suppliers.	In-house production using internal scrap and inputs from cooperatives; PCR (Post-Consumer Recycled) up to 30%.	Sandoval, Jaca and Ormazabal (2018): recycling as a strategy for closing the material loop.
Chemical recycling	Not mentioned.	Pyrolysis to convert waste into oil and subsequently produce resin.	Pérez-Ortega et al. (2021): technological innovation for greater circular autonomy.
Limitations	Dependence on availability in the national market.	Dependence on price, scale, and regulation.	Gagnon et al. (2022): infrastructure and cost as central barriers.

Table 16: Ensuring the renewable origin of materials
Source: Prepared by the author

The comparative analysis shows that Company A focuses on the economic and strategic benefits of the Circular Economy, prioritizing productive efficiency, resin reuse, and the optimization of internal processes, resulting in financial gains and the strengthening of institutional image. In contrast, Company B emphasizes environmental and social impacts, highlighting the reduction of pollution, the removal of plastics from the environment, the decrease in dependence on fossil resources, and the preservation of resources for future generations. While Company A focuses on the operationalization of circularity and competitiveness, Company B directs its efforts toward sustainability and intergenerational responsibility.

The observed practices are theoretically supported as they relate to the multiple benefits of the Circular Economy, encompassing environmental, economic, and social aspects. The literature indicates that circularity contributes to reducing environmental impacts, extending product life cycles, preserving the value of materials, and generating new business opportunities (Batwara et al., 2022; Evrard et al., 2021; Gagnon et al., 2022; Jugend et al., 2020). In addition, sustainable development is reinforced by balancing current consumption with the planet’s capacity for regeneration (Ellen MacArthur Foundation, 2019). These theoretical foundations justify the adoption of strategies that promote efficiency, material reuse, mitigation of environmental impacts, and institutional strengthening.

It can be observed that, despite their different approaches, both companies expand the benefits associated with the Circular Economy by integrating economic, social, and environmental gains into the packaging development process. This articulation demonstrates that different trajectories can converge to maximize circularity and strengthen sustainability in the sector.

Table 15 presents the benefits of the Circular Economy from the perspective of Companies A and B and establishes their relationship with the literature.

The comparative analysis shows that Company A presents a high-cost profile, concentrated on investments in machinery, process adaptation, product development, and the acquisition of recycled resins, reflecting a capital-intensive strategy dependent on scale and on the recognition of value by customers. In contrast, Company B faces less intensive costs in terms of direct investment, with a greater impact related to the price of renewable or recycled raw materials, supply volatility, and commercial and organizational efforts required for process adaptation and employee training. While Company A assumes significant initial financial risks, Company B seeks to dilute costs through scale and transfer part of them to the market, highlighting different strategic approaches to implementing the Circular Economy.

Dimension	Company A	Company B	Relationship with the Theory
Environmental	Reduction in the consumption of virgin raw materials; reuse of resins.	Removal of plastics from the environment; reduction of landfills and pollution.	Batwara et al. (2022): circularity as a strategy for reducing environmental impacts.
Economic	High initial investments, but efficiency gains in the medium/long term.	Reduction of indirect costs by avoiding waste of fossil resources.	Evrard et al. (2021): economic benefits arise from efficiency and innovation.
Social/ Intergenerational	Strengthening of institutional image and reputation as a sustainable brand.	Preservation of resources for future generations; positive impact on society.	Jugend et al. (2020): circularity as a means of ensuring future well-being.
Organizational	Strengthening of internal culture and market competitiveness.	Promotion of collective responsibility and advocacy for circularity in industry forums.	Diaz et al. (2021): stakeholder integration as a key factor for the Circular Economy.

Table 17: Benefits of the Circular Economy in packaging development: comparison between the companies
Source: Prepared by the author

The observed practices are theoretically supported by studies indicating that the costs of circularity go beyond initial investments in infrastructure and include operational, adaptation, transaction, and organizational costs, with financial returns typically expected only in the medium and long term, especially in the absence of regulatory incentives or purchasing scale (Gagnon et al., 2022). In addition, price sensitivity and consumer resistance constitute additional barriers to the adoption of circular solutions, as pointed out by Urbinati, Chiaroni, and Toletti (2019). These theoretical foundations justify the need for strategic planning, financial risk management, and market coordination to enable the implementation of the Circular Economy.

It can be observed that, despite differences in the structure and origin of costs, both companies face similar economic and strategic challenges, demonstrating that the transition toward circular practices requires balancing investments, operational efficiency, and market acceptance in order to consolidate circularity in the packaging sector.

Based on the responses from both companies, Table 16 presents a comparison between the costs faced by Companies A and B.

Cost category	Company A	Company B
Investment in machinery/ infrastructure	High — acquisition and adaptation of production lines (reported ≈ 30 million).	Low to moderate — many changes can be process-based; reduced investment when only material substitution is required.
Raw material cost	Increase (certified/special resins).	Significant and volatile increase (green/recycled resins + limited supply).
Processing cost	Initial increase (energy, maintenance, losses).	Varies depending on the process; may remain similar if the process does not change, but more expensive inputs increase overall costs.
Quality / technical adaptation costs	Testing, validation, consulting services, and laboratory control.	Training, production adjustments, and regulatory validation.
Certification / compliance costs	Certifications and external audits.	Same requirements; potential regulatory restrictions in certain applications (e.g., ANVISA).
Transaction / commercial costs	Commercial effort to sell circular product lines (marketing, sales)	Significant effort to convince customers and pass on costs; risk of losing sales.
Opportunity costs / market risk	Risk of investment obsolescence if customers do not adopt.	Risk of losing volume if the market does not accept a higher price.
Payback / expected benefit	Medium- to long-term payback; gains through brand image and access to new markets.	Payback dependent on scale; potential future profit with large-scale adoption.

Table 18: Comparison of costs associated with Circular Economy practices
Source: Prepared by the author

The comparative analysis shows that Company A focuses its efforts on reducing solid waste and reusing water, adopting a more operational and pragmatic approach to mitigating environmental impacts, while Company B adopts a more structured and comprehensive strategy, including life cycle assessment programs, long-term carbon emission targets, and a greater use of renewable energy. Company A prioritizes internal management of resources and waste, whereas Company B seeks to integrate corporate environmental commitments with international decarbonization standards, demonstrating different levels of maturity regarding the implementation of the Circular Economy.

The observed practices are theoretically supported as they relate to resource efficiency as a central pillar of the Circular Economy, associated with material reuse and water management (Dumée, 2022; Khan et al., 2021). In addition, the systematic measurement of environmental impacts and the monitoring of carbon emissions are highlighted as essential instruments to ensure the credibility and effectiveness of circular initiatives (Linder, Sarasini, and Van Loon, 2017). These theoretical foundations justify the adoption of practices aimed at reducing waste, promoting rational use of resources, and mitigating greenhouse gas emissions.

It can be observed that, although the companies adopt different strategies, both contribute to the reduction of relevant environmental impacts, demonstrating that different implementation paths for the Circular Economy can generate significant environmental benefits and strengthen sustainability in the packaging sector.

Table 17 summarizes the environmental impacts that Companies A and B seek to reduce through the Circular Economy.

Impact category	Company A	Company B
Solid waste	Reduction of waste generation and reuse of materials.	Mechanical and chemical recycling, with corporate targets for material recovery.
Water resource use	Treatment and reuse of industrial water.	Not emphasized, but includes efficiency in water consumption.
Carbon emissions	Reduction considered, but not detailed.	Monitoring through life cycle assessment (LCA); projects with negative emissions; targets through 2050.
Energy	Not detailed.	64% of energy sourced from renewable sources (solar and wind).
Toxic waste	Not mentioned.	Not explicitly addressed.

Table 19: Comparison of the impacts that companies seek to reduce through the Circular Economy
Source: Prepared by the author

The comparative analysis shows that Company A establishes more targeted and operational partnerships, focusing on recyclers to reinsert plastic waste into the production cycle, while Company B develops a broader and more structured network, involving cooperatives, international certifications, suppliers of sustainable materials, and its own pyrolysis and mechanical recycling infrastructure. The first adopts a practical and localized approach, focused on operational efficiency, while the second seeks to articulate multiple actors and processes, promoting integration on a global scale and greater robustness in the implementation of CE.

The observed practices are theoretically supported as they relate to interorganizational collaboration as a central mechanism to enable the flow of secondary materials and legitimize environmental practices (Elia, Gnoni and Tornese, 2017; Ellen MacArthur Foundation, 2019; Khan and Haleem, 2021; Wang, Burke and Zhang, 2022). The concept of “industrial symbiosis” also underpins the integration of different actors to optimize material and energy flows (Sandoval, Jaca and Ormazabal, 2018). Such references justify the adoption of strategic partnerships with recyclers, cooperatives, suppliers, and certification bodies, demonstrating alignment with the structuring principles of CE.

It is observed that, although the levels of maturity and scope of partnerships are different, both companies strengthen the circularity of their operations through collaboration with strategic actors, highlighting that well-structured alliances are essential to consolidate sustainable material cycles.

Table 18 presents a summary comparison between Companies A and B regarding partnerships.

Category	Company A	Company B
Recyclers	Partnerships to reuse plastics in second-line packaging.	Contracts with cooperatives (e.g., Pindamonhangaba city) to supply mechanical recycling and pyrolysis plant.
Sustainable suppliers	Not specified.	Purchase of inputs such as green PET in the market.
Certifications	Not mentioned.	ISCC Plus already obtained; in the process of new national and international certifications.
Internal structure	Not reported.	Partial self-sufficiency with mechanical and chemical recycling (pyrolysis).

Table 20: Comparison of Partnerships to Promote CE
Source: Prepared by the author

The comparative analysis shows that Company A focuses on the technical durability of packaging, prioritizing more resistant materials that allow multiple cycles of use and encourage reuse, while Company B adopts a broader approach, combining increased durability through production processes, such as lamination and coextrusion, with consumer-oriented design strategies, including zippers, transparent windows, and removable labels. The first emphasizes the robustness and reliability of packaging, while the second integrates aspects of social acceptance and functional redesign, demonstrating different paths to extend the useful life of packaging in the context of CE.

The practices adopted are theoretically supported as they relate to circular design and the extension of product life, aiming to reduce the demand for virgin raw materials and optimize the use of natural resources (Asif et al., 2021). The role of the consumer and the market in driving packaging redesign is aligned with discussions of circularity focused on reuse and post-use valorization (Amend et al., 2022). Other references highlight mechanisms of durability, modularity, and ease of disassembly as central strategies to extend the life cycle of packaging (Bressanelli et al., 2020; Joustra, Flipsen and Balkenende, 2021), justifying the adoption of the described approaches.

It is observed that, although the companies' strategies vary in scope and complexity, both contribute to extending the useful life of packaging, strengthening circularity by reducing waste and optimizing the use of resources throughout the life cycle.

Table 19 presents a summary of the strategies that Companies A and B use and also includes a comparison with what exists in theory.

Category	Company A	Company B	Relationship with the Theory
Technical durability	Resistant and high-quality packaging, enabling more than one cycle of use.	Processes such as lamination and coextrusion that increase the durability of films and containers.	Asif et al. (2021): extending the life cycle as a core axis of circularity.
Design for reuse	Not detailed.	Zippers in flexible packaging; transparent windows; removable labels to facilitate reuse.	Amend et al. (2022): modularity as facilitators of reuse.
Consumer reuse	Indirect incentive through material resistance.	Encouragement of secondary use (e.g., containers, stand-up packaging more reused).	Joustra, Flipsen and Balkenende (2021): active role of the consumer in the circularity cycle.

Table 21: Comparison of strategies to extend the useful life of packaging
Source: Prepared by the author

The comparative analysis shows that Company A focuses on innovative and pioneering solutions for circular packaging, such as Ecoprime, reusable cheese packaging, and the internal transformation of plastic waste into secondary products, reinforcing closed technical cycles and internal reuse. In contrast, Company B adopts an approach oriented toward industrial scale, using materials collected at selective collection points, labels with up to 50% PCR, and recycled bottle projects, integrating external partners and expanding circularity across different markets. While the first focuses on innovation and direct reuse, the second emphasizes systemic integration and large-scale impact.

These practices are theoretically supported as they relate to the concept of technical cycles and the reintroduction of materials into the production process, as pointed out by the Ellen MacArthur Foundation (2019). The integration of recycled materials into products with different applications and the valorization of secondary waste are aligned with the literature that emphasizes the need to reconnect packaging to the circularity cycle (Genovese et al., 2015; Niero and Kalbar, 2019). Such references justify the adoption of strategies that promote efficiency in resource use and the extension of the material life cycle.

It is observed that both companies materialize the principles of CE through concrete examples of packaging, either through internal innovation and reuse or through the integration of recyclables on an industrial scale, highlighting complementary trajectories that strengthen circularity and the sustainability of the sector.

Table 20 presents a comparison between the two companies with regard to circular packaging.

Category	Company A	Company B
Examples of products	Cheese packaging recycled into ice packaging; Ecoprime 100% recyclable; garbage bags and seedling bags from internal waste.	Biscuit packaging made from collected materials; recycled bottles; bottle labels with up to 50% PCR.
Highlighted innovation	Ecoprime as the first 100% recyclable shrink packaging in Brazil.	Pioneering use of PCR in labels and secondary packaging, with industrial-scale feasibility.
Origin of the material	Internal waste reused and recycled.	Materials collected in cooperatives and by the company's own collectors.
Scope of application	Focus on internal reuse and pioneering products.	Large-scale projects aimed at different market segments.

Table 22: Examples of circular packaging
Source: Prepared by the author

The comparison between the companies reveals distinct approaches regarding the incorporation of CFD (Circular Function Deployment) into their processes. Company A does not use the methodology in its projects, adopting circularity practices in a punctual manner and without systematic integration, which indicates an initial stage of formalization. In contrast, Company B shows signs of indirect adoption of concepts similar to CFD in areas such as R&D, innovation, and sustainability, demonstrating greater familiarity with management frameworks focused on circularity, although still without structured implementation. While one focuses on isolated experiences, the other is moving toward integrating circularity criteria into product development.

The use of CFD is directly related to the literature that identifies structured methodologies as essential for the systematic incorporation of CE principles from the early design phases, promoting alignment between innovation, sustainability, and market requirements (Vimal et al., 2022). This theoretical reference justifies that the adoption of formal tools can increase predictability and control over the process of integrating circularity, highlighting the relevance of frameworks such as CFD to optimize environmental and production outcomes.

It is observed that the difference in maturity between the companies regarding CFD reflects different levels of formalization and systematization of circularity in packaging development processes, with potential for future expansion among those that have not yet adopted the methodology in a structured manner.

The comparative analysis highlights different approaches by the companies regarding the influence of policies and regulations on the implementation of CE. Company A acts in a reactive manner, adapting to current regulations, such as the National Solid Waste Policy, state regulations, and ABNT technical standards, as well as sanitary requirements from Anvisa, without indications of proactive monitoring of regulatory changes. In contrast, Company B adopts a proactive stance, considering national legislation, international treaties, and mechanisms such as Extended Producer Responsibility and the Recycling Incentive Law, in addition to monitoring bills under discussion, which allows anticipation of regulatory impacts on the production and use of recycled materials. While one focuses on immediate compliance, the other integrates regulatory management into its circularity strategy in a broader manner.

The relevance of this approach is supported by the literature and legislation, which indicate that circularity management must reconcile compliance with existing standards and the ability to adapt to future scenarios. Bill No. 1874, of 2022, which establishes the National Circular Economy Policy (Brazil, 2022), reinforces the need for strategic alignment with emerging regulations, highlighting the role of international treaties and recycling incentive policies as instruments to promote reverse logistics and sustainable practices in packaging development.

It is observed that the difference in approach between the companies reflects different levels of regulatory and strategic maturity, with greater potential for anticipation and integration of circularity by those that actively monitor and incorporate legislative changes.

The comparative analysis highlights different perceptions of the companies regarding the demand for sustainable packaging by clients. Company A observes growing interest from large brands and exporters, but faces limitations in practical adoption due to additional costs. In contrast, Company B indicates that, although there is no direct requirement, there are frequent requests for alternatives, especially without aluminum, although not all projects proceed to approval. While one faces economic barriers in implementing explicit demands, the other records an emerging demand that has not yet translated into formal requirements, highlighting different levels of interaction with the consumer market.

The practices of the companies are supported by literature that discusses barriers to the adoption of circular products. Zikopoulos (2022) points out that consumers' environmental awareness is still insufficient to sustain effective market changes, and Gagnon et al. (2022) reinforce that higher costs and lack of consolidated demand hinder the implementation of circular practices. In addition, Pretner et al. (2021) highlight that the perception of sustainable products may impact purchase decisions, as some consumers associate recycled materials with lower quality. Evrard et al. (2021) complement this by indicating that, although consumers value environmental aspects, the conversion into purchasing practices is still partial. Each reference highlights theoretical elements that explain the limitations and opportunities reported by the companies in the adoption of sustainable packaging.

It is observed that, despite differences in the way they interact with clients, both companies reflect market trends that face structural obstacles, mainly related to costs and perceptions of quality, while signs of change emerge that point to greater interest in environmentally responsible solutions.

A comparative table between Companies A and B together with concepts from the literature was prepared to present some aspects related to clients and sustainable packaging. This comparison can be seen in Table 21.

Aspect	Company A	Company B	Relationship with the Theory
Customer requirements	Interest from large brands and exporters, but limited adoption.	They do not require it, but request alternatives, especially without aluminum.	Consumers' environmental awareness is still low (Zikopoulos, 2022).
Barriers	Additional cost prevents adoption on a larger scale.	Projects are often not approved.	Higher costs and lack of consolidated demand are barriers (Gagnon et al., 2022).
Value perception	Initial interest does not convert into action due to cost.	Growing movement toward circular alternatives.	Consumers may associate circular products with lower quality (Pretner et al., 2021).

Table 23: Comparison of some aspects between customers and sustainable packaging
Source: Prepared by the author

The comparative analysis shows different forms of requests for sustainable packaging between the companies. Company A receives demands both from contractual requirements and environmental certifications and from commercial negotiations, in addition to developing internal initiatives to anticipate trends, such as Ecoprime. In contrast, Company B identifies requests originating mainly from strategic guidelines of the headquarters or from the top management of clients, reflecting top-down decisions based on global commitments. While one combines external pressures and internal strategies, the other responds to higher-level corporate guidelines, highlighting different channels that stimulate the adoption of circular practices.

The practices reported by the companies are theoretically supported by literature that emphasizes multiple levels of pressure for the implementation of CE. Geissdoerfer et al. (2017) highlight the importance of external demands and internal strategies in advancing circularity, while Loiseau et al. (2016) and Sandoval, Jaca and Ormazabal (2018) emphasize the role of international pressures. Zikopoulos (2022) indicates that consumers' environmental awareness is still not sufficient for significant market changes, and Gagnon et al. (2022) highlight barriers such as high costs and lack of consolidated demand. Pretner et al. (2021) point out that the perception of value of circular products influences purchasing decisions, reinforcing obstacles to adoption. Finally, the Ellen MacArthur Foundation (2019) and Joustra et al. (2022) recommend the integration of tools such as life cycle assessment and design for circularity to support sustainable decisions. Each reference explains theoretical aspects that justify the challenges and strategies observed.

It is observed that, although the channels of request vary between internal initiatives, contractual requirements, or corporate guidelines, both companies face similar limitations related to costs, perception of quality, and approval processes, highlighting that multiple factors influence the practical implementation of sustainable packaging.

Table 22 presents a comparison between Companies A and B regarding requests for sustainable packaging from clients, and also includes a comparison with concepts present in the literature.

The comparative analysis highlights significant differences between the companies in the implementation of CE practices. Company A faces challenges related to high investment costs in technologies, machinery, and certified recycled raw materials, technical difficulties in maintaining packaging performance, logistical barriers, and initial market resistance. In contrast, Company B internalized circularity from its foundation, incorporating practices such as reverse logistics, recycling, and environmental awareness into its organizational culture, which minimizes operational obstacles and facilitates adaptation to changes without significant impacts. While one organization experiences the transition to circular models, the other exemplifies the benefits of a trajectory historically aligned with sustainability.

Request channel	Company A	Company B	Relationship with the Theory
Contractual requirement / certification	Requests linked to contracts and certifications, especially from large clients and exporters.	It may occur, but it is more common due to headquarters directives.	Pressure at different levels (micro, meso and macro) induces circularity (Sandoval, Jaca and Ormazabal, 2018).
Commercial meetings / suggestions	Demands arise in negotiations or meetings and may generate internal projects.	Clients request alternatives, but many do not reach approval.	Market barriers: costs and uncertain demand (Gagnon et al., 2022).
Headquarters directive / top-down	Less frequent, but occurs in some specific cases.	Frequent: clients determine sustainable packaging based on strategic guidance.	Corporate governance and business models as drivers of circularity (Loiseau et al., 2016).
Internal initiative (R&D)	Proactive development, such as Ecoprime, anticipating trends.	There is also integration of R&D with sustainability at the corporate scale.	Proactive innovation and design for circularity are central strategies (Geissdoerfer et al., 2017).
Practical outcome	High interest, but limited adoption due to additional cost.	Recurring requests, but many are not approved.	Environmental awareness still insufficient for large-scale change (Pretner et al., 2021).

Table 24: Forms of requests for sustainable packaging
Source: Prepared by the author

These practices and challenges are theoretically supported. Gagnon et al. (2022) and Zikopoulos (2022) indicate that high costs, unprepared suppliers, technical difficulties, and market resistance are common barriers to the implementation of circularity. Pretner et al. (2021) highlights that the perception of lower quality of recycled materials may hinder the adoption of circular products. On the other hand, Jiang et al. (2021) shows that companies that internalize circular logic from their creation develop regenerative business models capable of overcoming market barriers and engaging employees and partners in sustainable practices. Each reference theoretically explains the obstacles and strategies observed in the two companies.

The comparison shows that the historical trajectory and the level of maturity in sustainability directly influence the intensity of the obstacles faced, highlighting that the early internalization of CE contributes to a smoother and more integrated implementation.

A table containing a comparison of the barriers or obstacles that Companies A and B faced was prepared. This table also relates them to the theory present in the literature. This information is presented in Table 23.

Aspect	Company A	Company B	Relationship with the Theory
Investment costs	High costs with machines, technologies, and recycled raw materials.	Does not identify significant additional costs.	High costs are a structural barrier to circularity (Gagnon et al., 2022).
Technical challenges	Ensuring quality and performance equivalent to conventional packaging.	Does not report relevant technical challenges.	Technical resistance related to the performance of recycled materials (Pretner et al., 2021).
Logistical issues	Difficulty in purchasing inputs and adapting internal processes.	Processes already adjusted to circular logic from the outset.	Lack of prepared suppliers is a common barrier (Joustra et al., 2022).
Market resistance	Suppliers and clients resistant to higher-cost sustainable solutions.	Circularity culture incorporated, with a focus on internal campaigns.	Market acceptance depends on cultural engagement and regenerative models (Zikopoulos, 2022).
Organizational culture	Gradual adaptation process to circular logic.	Circularity incorporated as part of the "organizational DNA."	Companies with a sustainable culture from the outset face fewer barriers (Jiang et al., 2021).

Table 25: Obstacles to implement CE
Source: Prepared by the author

The comparative analysis highlights distinct approaches to overcoming challenges in implementing CE. Company A faced internal obstacles related to high costs and technical limitations, which were mitigated through planned investments in new technologies, materials, and processes, transforming barriers into strategic opportunities. In contrast, Company B demonstrates operational maturity due to the incorporation of circularity since the origin of the business, facing difficulties mainly external, related to customers' perception of value and the market's willingness to pay for sustainable solutions. While one organization mobilized financial resources to enable circularity, the other concentrates efforts on communication and market engagement.

These practices are supported by the literature, which highlights mechanisms for overcoming barriers in CE. Ghisellini, Cialani and Ulgiati (2016) show that investment in innovation and new technologies is essential to overcome technical and market limitations, reinforcing the strategy of planned resource allocation. Gagnon et al. (2022) indicate that high costs and the absence of consolidated demand require strategic planning, aligned with the investment posture of Company A. Pretner et al. (2021) explain that the difficulty of adoption by clients results from the perception of lower quality or higher cost, an aspect identified in the experience of Company B. Zikopoulos (2022) emphasizes that engagement and educational campaigns are essential to increase the acceptance of circular products. Each reference theoretically justifies the practices observed and the way the challenges were addressed.

The study of the two organizations demonstrates that overcoming obstacles depends both on internal investments and strategic vision and on external communication and the valuation of circular solutions, highlighting that multiple factors must be considered to enable the transition to circular production and consumption models.

Table 24 presents a summary that was prepared to show some aspects related to the literature and how Companies A and B overcame the challenges in the implementation of CE.

Aspect	Company A	Company B	Relationship with the Theory
Main strategy	Planned financial investment in technologies and materials.	Focus on convincing clients about the value of circular solutions.	Investments in innovation as a key to overcoming barriers (Ghisellini, Cialani and Ulgiati, 2016).
Nature of the challenge	High costs and the need for technological adaptation.	Market resistance, with price as the decisive criterion.	Cost barriers and value perception limit adoption (Gagnon et al., 2022).
Adopted vision	Courage and future vision to sustain changes.	Circularity already in the DNA, but clients still prioritize cost.	Proactive companies overcome barriers through strategic planning (Ghisellini, Cialani and Ulgiati, 2016).
Suggested tools	Gradual and strategic investments in R&D and infrastructure.	Engagement and persuasion of stakeholders.	LCA and design for circularity as instruments of legitimation (Ghisellini, Cialani and Ulgiati, 2016).

Table 26: Overcoming the challenges to implement CE
Source: Prepared by the author

The comparative analysis highlights significant differences in the management of the packaging life cycle between Companies A and B. Company A adopts a more reactive stance, without structured reverse logistics programs or formal incentives for packaging return, limiting itself to monitoring trends and evaluating future possibilities, which indicates partial integration of circularity into its operational strategy. In contrast, Company B demonstrates a systemic and integrated approach, with personnel dedicated to sustainability, redesign practices to improve recyclability, mechanical and advanced recycling, and the reintegration of recycled resin into new products, assuming an active role in reverse logistics and demonstrating a consolidated operational application of CE.

These practices relate to the theoretical foundation, which emphasizes the need to close material loops and reduce waste throughout the entire production chain

(Dantas et al., 2021). Bag et al. (2021) highlight that many companies still limit themselves to punctual post-consumption actions, while more comprehensive and collaborative models allow the incorporation of the entire circularity cycle. Each reference provides theoretical support for the observed differences, showing that the effective implementation of CE depends on the systematization of processes and the integration of initiatives from design to material reinsertion.

The analysis demonstrates that the management of the packaging life cycle requires an integrated structure, combining circular design, reverse logistics, and consumer engagement, showing that organizations more mature in CE are able to operationalize circularity in a continuous and systemic manner.

To summarize the responses and present a comparison, a table was prepared and can be seen in Table 25.

Aspect	Company A	Company B	Relationship with the Theory
Reverse logistics	Nonexistent, responsibility of the client.	Direct involvement in reverse logistics programs.	Reverse logistics is essential to close the cycle (Khan et al., 2021).
Recycling/ Reuse	There is no formal program, only monitoring of trends.	Mechanical and advanced recycling with reinsertion of recycled resins into new packaging.	Closing material cycles (Wang, Burke and Zhang, 2022).
Strategic approach	Reactive, depending on future legislation and client demands.	Proactive and systemic, integrating design, consumption, collection, and recycling.	Circularity as an integrated business model (Hobson, 2016).
Maturity of the practice	Initial stage.	Advanced stage, serving as a reference in Latin America.	Differences in maturity are common among companies in circular transition (Hofstra and Huisingh, 2014).

Table 27: Packaging life cycle management
Source: Prepared by the author

The comparative analysis shows that both companies present limitations regarding the monitoring of the relationship between clients and CE, although for different reasons. Company A does not have structured systems to track the final destination of packaging, limiting its actions to the production process and restricting the integration of circularity into the consumption cycle. Company B, despite having consolidated practices in reverse logistics and mechanical recycling, also does not monitor consumer behavior, revealing a gap in the incorporation of the end user as an active agent in closing material cycles.

This scenario is related to the theoretical foundation, which emphasizes that CE must involve the entire value chain, including consumers and regulatory bodies. Dantas et al. (2021) highlight that the absence of systematic monitoring of product use and disposal constitutes an obstacle to closing cycles. Genovese et al. (2015) and Wang, Burke and Zhang (2022) indicate that feedback and traceability mechanisms are essential to redesign strategies, identify bottlenecks, and foster circularity in a systemic way. These theoretical references justify the need to integrate actions that enable monitoring of end-user behavior and improve the effectiveness of circularity.

The analysis shows that the consolidation of CE requires post-consumption engagement and monitoring strategies, including interactive reverse logistics systems and digital tools that enable the tracking of disposal flows, reinforcing the importance of considering the client as an active part of the circular cycle.

The comparative analysis highlights that the companies present different levels of consumer involvement in the packaging life cycle. Company A carried out evaluations of return and reuse programs; however, the low adherence of clients, especially micro and small entrepreneurs, keeps the initiatives in an exploratory phase, without structured reverse logistics or buy-back programs. In contrast, Company B develops a pilot project in partnership with a large client and a cooperative, in which post-consumption packaging is processed and transformed into PCR resin reintegrated into the production chain, showing a more consolidated circularity strategy and integrating the consumer as an active agent in the reuse cycle.

This scenario relates to the theoretical foundation that emphasizes the importance of engaging all actors in the value chain for the effectiveness of CE. Sandoval, Jaca and Ormazabal (2018) highlight the relevance of network collaboration and industrial symbiosis, indicating that corporate action alone is not sufficient to close material cycles. Ghisellini, Cialani and Ulgiati (2016) reinforce that programs encouraging product return can increase the efficiency of recycling chains. These references justify the need to integrate consumers and clients into circular processes to consolidate reuse practices.

The companies demonstrate different levels of maturity in integrating consumers into circularity. While one adopts an exploratory and reactive stance in response to low adherence, the other implements structured and collaborative actions, showing that proactive strategies can generate environmental and competitive benefits in the context of CE.

Table 26 presents some elements of customer involvement in relation to the packaging life cycle and, in this sense, a comparison of the responses from Companies A and B was carried out together with a relation to the theory.

Aspect	Company A	Company B	Relationship with the Theory
Return programs	Evaluated incentives and reverse logistics, but without significant adherence.	Pilot project with a client and a cooperative to collect packaging and transform it into PCR resin.	Value chain engagement is essential (Elia, Gnoni and Tornese, 2017).
Customer profile	Mostly micro and small entrepreneurs, with little engagement in circularity initiatives.	Large clients willing to cooperate in circular economy projects.	Different customer profiles impact the feasibility of circular practices (Vihma and Moora, 2020).
Current stage	Exploratory, without consolidated initiatives.	In a testing phase, with positive results and a tendency for expansion.	Return programs increase cycle efficiency (Ghisellini, Cialani and Ulgiati, 2016).
Level of maturity	Low, with punctual initiatives.	Medium/high, with structured partnerships in progress.	Circularity requires cooperation between companies, clients, and cooperatives – several companies (Wang, Burke and Zhang, 2022).

Table 28: Customer involvement in the packaging life cycle
Source: Prepared by the author

The comparative analysis shows distinct approaches to collecting and using customer feedback regarding packaging and CE. Company A uses commercial service and post-sales follow-up to understand customer perceptions and implement improvements in sustainable and recyclable packaging, adjusting aspects such as practicality, resistance, and environmental communication. In contrast, Company B conducts indirect monitoring through annual satisfaction surveys, with superficial questions about sustainability, without a specific feedback protocol focused on circularity, indicating a more generalist model that is less integrated with CE practices.

This scenario is supported by the literature, which highlights the importance of integrating the consumer as an active agent in the sustainable innovation process. Sandoval, Jaca and Ormazabal (2018) emphasize that dialogue with stakeholders constitutes one of the pillars of CE, making it necessary to create mechanisms that allow the production system to be fed back with perceptions and demands from end users. These references justify the practice of using feedback to guide adjustments and improvements, reinforcing the need for active customer engagement in the product life cycle.

It is observed that the systematic incorporation of feedback contributes to improving packaging sustainability and strengthening the circular logic. While one company practically applies the information received to promote improvements, the other presents an opportunity to expand consumer involvement and align its actions with the principles of CE.

Regarding the collection of customer feedback, Table 27 presents a comparison based on the responses of Companies A and B.

Aspect	Company A	Company B
Collection method	Commercial service, direct conversations, and post-sales follow-up.	Annual satisfaction survey, with few questions about sustainability.
Use of feedback	Implementation of improvements in recyclable and sustainable packaging (practicality, resistance).	Contact only in case of detractor responses (none so far).
Focus on circularity	Directed and applied to the sustainable product line.	Generalist and seeks to act directly with clients.
Maturity of the practice	Medium/high – feedback integrated into sustainability strategies.	Low – absence of a specific system.

Table 29: Customer involvement in the packaging life cycle
Source: Prepared by the author

The comparative analysis shows differences in the perception of the benefits of circular packaging between the companies. Company A presents benefits perceived directly by clients, including strengthening of brand image, increased commercial appeal, competitive differentiation, and practical advantages such as functionality and cost reduction. In contrast, Company B experiences these benefits indirectly, through sector awards and repurchases of packaging, without clear measurement of the perception of end consumers, indicating less proximity to the user in evaluating the value of circular solutions.

The literature reinforces that circular products can generate intrinsic value by diverting waste from landfills and meeting consumers' environmental values (Evrard et al., 2021; Pretner et al., 2021). In addition, circular practices can provide reputation gains, brand strengthening, and business opportunities, generating competitive advantage by aligning sustainability and innovation (Hobson, 2016; Korhonen et al., 2018). These references justify the importance of translating CE into benefits perceived by the market, demonstrating how the implementation of sustainable solutions adds both environmental and economic value.

The perception of benefits is directly related to the company's proximity to the final consumer and the maturity of its evaluation mechanisms. While one company demonstrates tangible and measurable impacts for its clients, the other depends on institutional recognition, indicating that different strategies may influence the internalization of the value of circularity.

Regarding the benefits perceived by clients, Table 28 presents a comparison based on the responses of Companies A and B.

Aspect	Company A	Company B
Perceived benefits	Brand strengthening; commercial appeal; competitive differentiation; practicality; long-term cost reduction.	Industry awards and repurchases, without direct access to end consumer perception.
Impact focus	Direct on the client and the end consumer.	Indirect, with institutional recognition.

Table 30: Benefits perceived by clients
Source: Prepared by the author

The comparison between the companies shows distinct approaches to measuring the results of CE initiatives. Company A uses a simplified model, based on internal surveys and periodic analyses of the use of recycled materials and the performance of sustainable packaging, allowing adjustments and continuous improvement in a qualitative manner. In contrast, Company B adopts a more formalized and quantitative methodology, considering indicators such as reduction in the use of virgin raw materials, increase in recycled content, volume of recycled materials, and reduction of emissions, promoting structured monitoring and objective communication of results.

The literature reinforces that measurement is essential to verify environmental, economic, and social gains in circularity initiatives (Pauliuk, 2018). The lack of consolidated metrics represents a barrier to the effective implementation of CE, while clear indicators allow performance evaluation and guide continuous improvements (Figge et al., 2018). These theoretical references justify the importance of adopting systematic evaluation mechanisms, showing that monitoring practices contribute to the effectiveness of circular initiatives.

It is observed that the level of formalization and detail of the metrics differentiates the maturity level of the companies, with one still in an initial stage of structuring and the other advancing toward robust quantitative indicators, showing different ways of monitoring and improving circularity results.

Regarding the benefits perceived by clients, Table 29 presents a comparison based on the responses of Companies A and B together with the relation to the theory.

Aspect	Company A	Company B	Relationship with the Theory
Evaluation method	Internal surveys and periodic analyses.	Formal and quantitative indicators (reduction of virgin raw materials, increase in recycled content, emissions).	Measurement is essential for the effectiveness of the circular economy (Pauliuk, 2018).
Focus	Use of recycled materials and performance of sustainable packaging.	Quantitative impact on inputs, emissions, and recycling volume.	Metrics reduce barriers and increase effectiveness (Figge et al., 2018).
Maturity	Initial stage, qualitative monitoring.	Advanced stage, structured quantitative monitoring.	The literature advocates continuous evolution in evaluation systems (Linder, Sarasini and Van Loon, 2017).

Table 31: Measurement and evaluation of CE results
Source: Prepared by the author

The comparative analysis of the companies reveals different approaches to monitoring CE initiatives. Company A focuses on internal indicators related to the use of recycled materials and the performance of its sustainable solutions, providing qualitative information that guides adjustments and strategic planning. In contrast, Company B uses detailed quantitative metrics, such as tons of recycled plastic, percentage of recycled content, reduction of carbon intensity, and volume of virgin raw materials avoided, enabling objective evaluation of performance and alignment with international sustainability standards.

The relevance of metrics in the context of CE is highlighted in the literature, showing that clear indicators make it possible to measure results, identify opportunities for improvement, and track material flows, longevity, and monetary value (Niero and Kalbar, 2019; Figge et al., 2018). The definition of structured metrics is considered essential for the effectiveness of circular practices (Linder, Sarasini and Van Loon, 2017), while quantitative indicators help standardize and compare initiatives across sectors (Pauliuk, 2018). These theoretical references justify the adoption of different forms of measurement, demonstrating that both qualitative and quantitative approaches contribute to the evolution of circularity practices.

It is observed that the maturity of the companies in the use of metrics varies, with one still in an initial phase of internal monitoring and the other consolidating a robust and quantitative system, demonstrating different trajectories to evaluate and strengthen the results of CE initiatives.

Table 30 presents a comparison based on the responses of Companies A and B together with the relation to the theory.

Aspect	Company A	Company B	Relationship with the Theory
Indicators used	Use of recycled materials and performance of sustainable solutions.	Tons of recycled plastic; % of recycled content; carbon reduction; virgin inputs avoided.	Metrics are essential to validate progress and overcome barriers (Linder, Sarasini and Van Loon, 2017).
Approach	Qualitative and internal monitoring.	Quantitative and structured monitoring.	Alignment with good practices (Pauliuk, 2018).
Maturity	Initial stage.	Advanced stage, with a focus on comparable results.	Different levels of evolution reflect different degrees of circularity integration (Figge et al., 2018).

Table 32: Metrics used in CE monitoring
Source: Prepared by the author

5.3.1 Case synthesis

The analysis of the responses provided by the two investigated companies (Company A and Company B) highlights different stages of maturity and distinct strategies regarding the integration of the circular economy in packaging development. Although both recognize the relevance of this paradigm for the plastic and flexible packaging sector, their trajectories reveal nuances ranging from implementation challenges to the way results are measured.

In the case of Company A, a posture marked by the gradual search for adaptation to market demands and regulatory requirements can be observed. The company highlights pioneering initiatives such as the development of Ecoprime, but also reveals significant barriers, especially related to costs, technical adequacy, and customer resistance to accepting sustainable packaging with higher added value. Its approach is still more centered on internal and qualitative monitoring, without the adoption of robust metrics that allow systematic measurement of the impacts of its initiatives.

On the other hand, Company B demonstrates a more consolidated integration into the circular economy, standing out as one of the largest recyclers in Latin America.

Its practices go beyond packaging redesign and the use of recycled materials, encompassing the entire circularity chain: from collection and reverse logistics to mechanical and chemical recycling. The company invests in clear quantitative indicators, such as tons of recycled plastic, reduction of carbon intensity, and percentage of recycled content, aligning with international standards of measurement and transparency. This posture indicates a higher stage of maturity, in which the circular economy is not merely a marketing or regulatory compliance strategy, but a central axis of corporate governance.

Another relevant point is the difference in the perception of barriers and challenges. While Company A identifies high investment costs and customer resistance as the main obstacles, Company B states that it has not faced significant barriers, since circularity is already part of its “organizational DNA.” However, when analyzed critically, it can be noted that even in Company B there are difficulties associated with customer awareness, whose focus often remains on immediate cost rather than on the long-term environmental benefits.

The relationship with stakeholders also presents important contrasts. Company A works in a more reactive and personalized manner, responding to specific customer demands and promoting technical dialogue according to the interest of each partner. Company B, on the other hand, develops a broader and more integrated ecosystem, involving cooperatives, certification bodies, suppliers, and clients in joint projects, some of them structured through reverse logistics programs.

Finally, with regard to the perception of value, both companies recognize that clients perceive benefits such as brand strengthening, market appeal, and competitive differentiation. However, the reports indicate that these symbolic gains do not yet fully translate into consolidated purchasing practices, especially among smaller clients. This finding reinforces the need for more consistent public policies and regulatory incentives to promote the large-scale adoption of circular solutions.

In summary, it can be concluded that Company A and Company B illustrate two distinct stages in the transition to the circular economy in the packaging sector. While the first advances gradually and faces structural barriers, the second presents greater consolidation and systemic integration. Nevertheless, both reinforce the main points identified in the theoretical foundation: the relevance of circularity for competitiveness, the challenges related to costs and customer adoption, and the need for clear metrics and collaboration networks to enable the transition. These findings contribute to understanding how companies of different sizes and maturity levels respond to environmental and market pressures, offering relevant insights for the formulation of business strategies and public policies aimed at sustainable development.

Table 31 presents a general synthesis comparing Companies A and B in the main aspects investigated for each company. Thus, Table 31 allows an objective visualization of the similarities and, especially, the differences between Company A and Company B with regard to the implementation of the circular economy in packaging development. This comparison reinforces that, although both recognize the relevance of the topic and have consistent initiatives, they are at different stages of organizational maturity.

Dimension	Company A	Company B
Decision to adopt the circular economy	Motivated by regulatory requirements and environmental commitment; strategic leadership decision; investments in machinery and innovation (≈ US$ 30 million).	Originated as a recycler; natural evolution toward reverse logistics and circularity; organizational DNA oriented toward sustainability.
Long-term vision	Become a national reference in sustainable packaging; expansion of recyclable product lines and reverse logistics programs.	Long-term strategic planning (5, 10, 20 years) with environmental targets; focus on renewable energy and reduction in fossil use.
Strategies and practices	Development of recyclable products (e.g., Ecoprime), reduction of film thickness, design for recycling, partnerships, and internal training.	Offering sustainable structures even without explicit demand; development of monomaterials; addressing the cost challenge.
Stakeholders involved	Board of directors, R&D, Engineering, certified suppliers, recyclers, clients, and cooperatives.	Corporate sustainability and innovation area; executive board; clients; cooperatives; suppliers.
Internal awareness	Training and information sharing with the team, still in a gradual manner.	Continuous and visible campaigns (posters, calendars, internal media); strong advocacy for plastic circularity.
Awareness among partners/clients	Technical dialogue, guidance on certifications and trends.	Presentations during client visits and forums; integration with cooperatives and partner companies in recycling projects.

Table 33: General synthesis and comparison of the companies – part 1
Source: Prepared by the author

Dimension	Company A	Company B
Goals and objectives	Replacement of virgin plastic, expansion of recyclable product lines, environmental certifications, and customer awareness.	Continuous offering of sustainable solutions; integration of sustainability targets into all R&D activities of the group.
Barriers faced	High costs, technical challenges, and resistance from clients and suppliers.	Does not identify significant internal barriers; the main difficulties are related to acceptance and price for clients.
Materials used	Polyolefin resins (PE, PP) and high molecular weight polymers.	Diversity of plastics (PET, BOPP, BOPE etc.); use of recycled materials; limitations due to legislation (e.g., PVC in food).
Renewable sources	Prioritizes certified suppliers; monitoring of trends, but with market limitations.	Limited use of green polyethylene (sugarcane); strong involvement in mechanical and chemical recycling.
Benefits of circularity	Reduction in the consumption of virgin raw materials, strengthening of brand image, and alignment with the sustainable market.	Reduction of dumps and landfills; lower consumption of fossil resources; environmental benefits for future generations.
Associated costs	High, with significant investments in machinery and technology.	Costs fall on the price of raw materials; productively there is no difference; the cost is passed on to the client.
Targeted environmental impacts	Reduction of waste, treatment and reuse of water, and lower consumption of natural resources.	Reduction of carbon emissions, use of 64% renewable energy, and product life cycle programs.
Established partnerships	Recyclers, certified suppliers, and laboratories.	Cooperatives, ISCC Plus certifications, suppliers of sustainable materials, and pyrolysis and recycling plants.
Extension of packaging life span	Development of reusable and resistant packaging.	The production process naturally extends life span; design and consumer demands influence redesign (zipper, window, stand-up pouches).
Practical examples	Ecoprime; cheese packaging recycled into garbage bags and seedling bags.	Biscuit packaging with PCR; bottle labels with up to 50% PCR; reverse logistics projects in partnership with clients.
Life cycle and reverse logistics	Does not collect post-consumption packaging; evaluates future possibilities.	Operations across the entire circular chain; largest recycler in Latin America; consolidated reverse logistics.
Customer feedback	Collected through commercial service; led to the expansion of the sustainable product line.	Annual satisfaction surveys with few questions about sustainability; low specific feedback.
Benefits perceived by clients	Positive image, market appeal, differentiation, and alignment with certifications.	Indirect return through repurchases and awards, without documented direct perception.
Measurement of results	Internal surveys and periodic analyses, without clear indicators.	Robust metrics: tons recycled, % of recycled content in packaging, reduction of carbon and virgin raw materials.
Metrics used	Qualitative internal indicators regarding the use of recycled materials.	Clear and internationally recognized quantitative indicators.

Table 34: General synthesis and comparison of the companies – part 2
Source: Prepared by the author

After conducting an in-depth analysis of the cases presented, the proposed model (which can be seen in Figure 14) was revisited to incorporate the changes observed in the case analysis, so that it better reflects the reality of the analyzed plastic packaging companies, aiming to present the activities in detail for each stage. The adjusted model can be seen in Chapter 6.

6. Adjusted proposed model

In this chapter, the adjusted proposed model will be presented according to what was observed in the cases presented in Chapter 5. The verification of the model's adequacy carried out by the two companies from the case study is also presented and, finally, the final model with its validated adequacy.

After analyzing the information from the companies examined in the case study, the model was adjusted to better describe the packaging development process. Figure 19 presents the adjusted model.

In the following sections, each stage will be explained in detail.

6.1 Discovery: Packaging

The process begins with the arrival of a new request, which may come either from an existing client or from a new client. At this stage, it is important to define the initial expectations regarding the packaging to be produced, including deadlines, volumes, and specific requirements. Next, the company needs to identify the client's needs and translate them into an initial project, which will serve as the basis for the following stages.

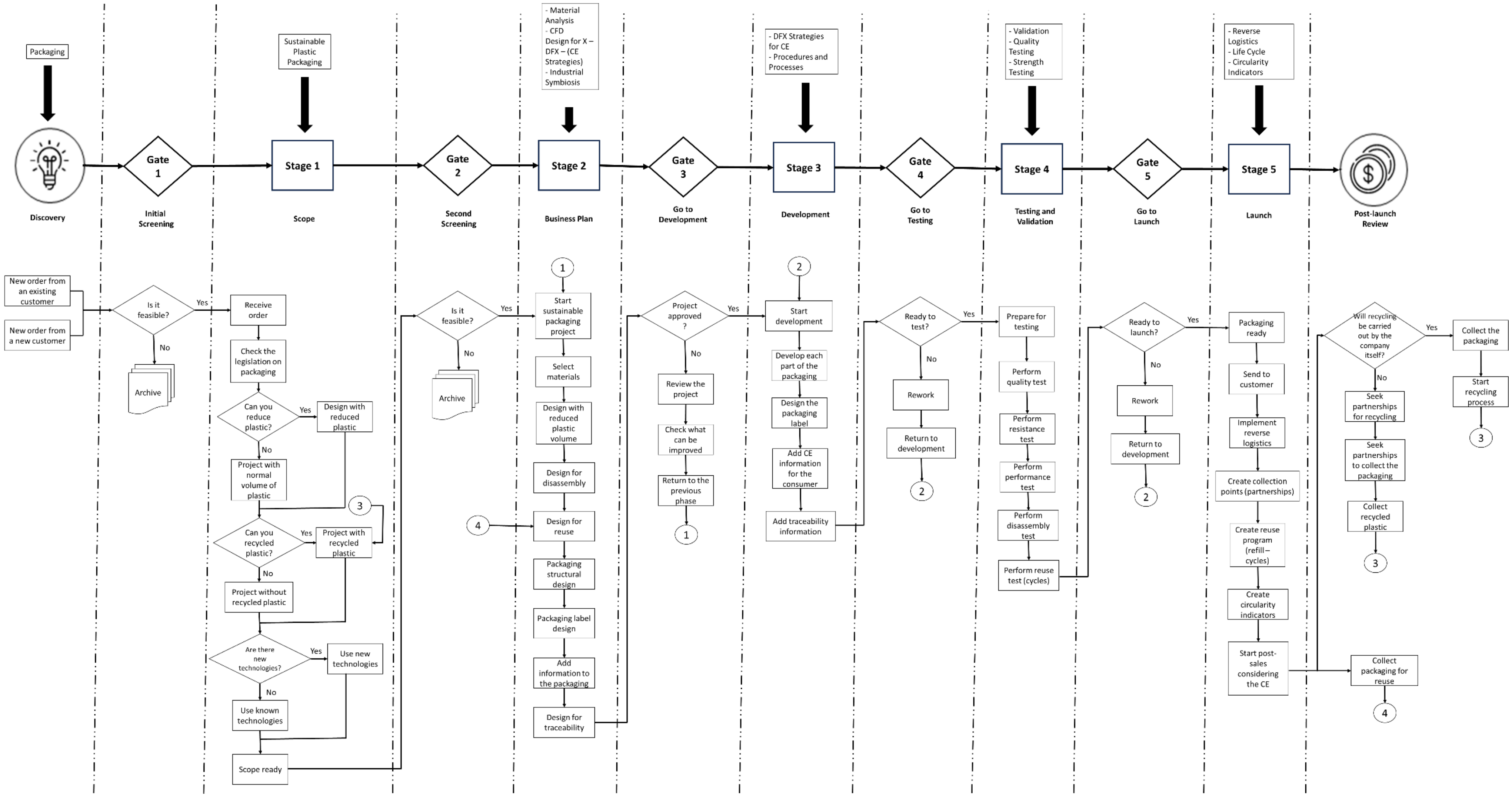

Figure 19: PDP model adjusted after the analysis
Source: prepared by the author

After the request, the first basic feasibility analysis is carried out (Gate 1). The company must answer the question: “Are there conditions to fulfill this request?” This filter takes into account technical capacity, available equipment, previous experience, and legal requirements. If it is identified that the request cannot be fulfilled, it is archived in a documented manner. If it is feasible, the process proceeds to Stage 1.

Figure 20 presents the discovery stage and the first gate.

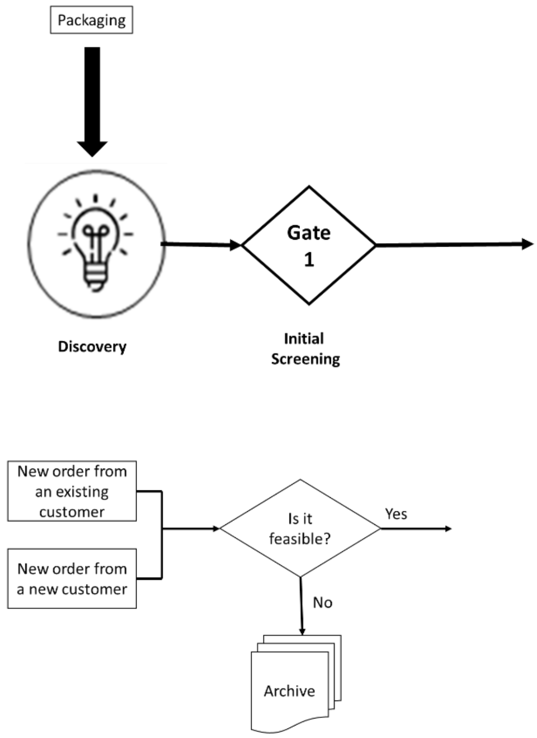

Figure 20: Activities of the discovery stage
Source: prepared by the author

6.2 Stage 1: Scope – Sustainable Plastic Packaging

Upon receiving the request, the scope of the plastic packaging development project begins. For this purpose, it is necessary to verify the applicable legislation, since depending on the type of product to be packaged, there is specific regulation. Packaging must comply with labeling standards, safety requirements, and environmental regulations. This verification is critical because failure to comply with legal obligations may have serious consequences and may even make the project unfeasible.

The second point of initial analysis is the possibility of reducing the amount of plastic. This involves rethinking the design to decrease thickness, eliminate parts, or optimize geometry. Reducing the consumption of virgin raw material has a significant impact on sustainability, but it must be balanced with the strength and functionality of the packaging. The project may also proceed without reducing the amount of plastic.

Another point that needs to be analyzed is the possibility of using recycled plastic in the project. The use of post-consumer or post-industrial recycled material strengthens sustainability commitments and improves circularity indicators. Thus, the recycled material may originate from leftovers from the packaging production process itself or from packaging that has been collected, so that all the plastic goes through the recycling process to be used as a new input in the packaging process. However, it is necessary to validate the quality of the material, its availability at scale, and its compatibility with legal requirements. This stage requires integration with suppliers and preliminary testing of properties. The project scope may proceed without using recycled materials.

Another activity in the initial screening is the investigation of new technologies applicable to the project. This may include new polymers, additives that improve recyclability, or even the use of better machines. If viable technologies exist, they may be adopted, increasing the competitive advantage. If no innovation is available or applicable, the portfolio of already consolidated technologies is used.

Once the screenings are approved, the project scope document is prepared. The objective here is to consolidate all the requirements identified up to this point in a document that may include, for example: packaging performance objectives, sustainability requirements (such as targets for mass reduction or percentage of recycled content), cost limits, as well as legal and commercial requirements.

Before proceeding to the next stage, a second feasibility check is carried out. Unlike the first, this analysis is more robust and may include, for example: cost estimates, supplier evaluation, production timelines, and risk analysis. If it is concluded that the project cannot be executed within the defined parameters, it may be reformulated or archived. If the answer is positive, the project advances to the business plan phase (Stage 2).

Figure 21 presents the part of Stage 1 that refers to the scope.

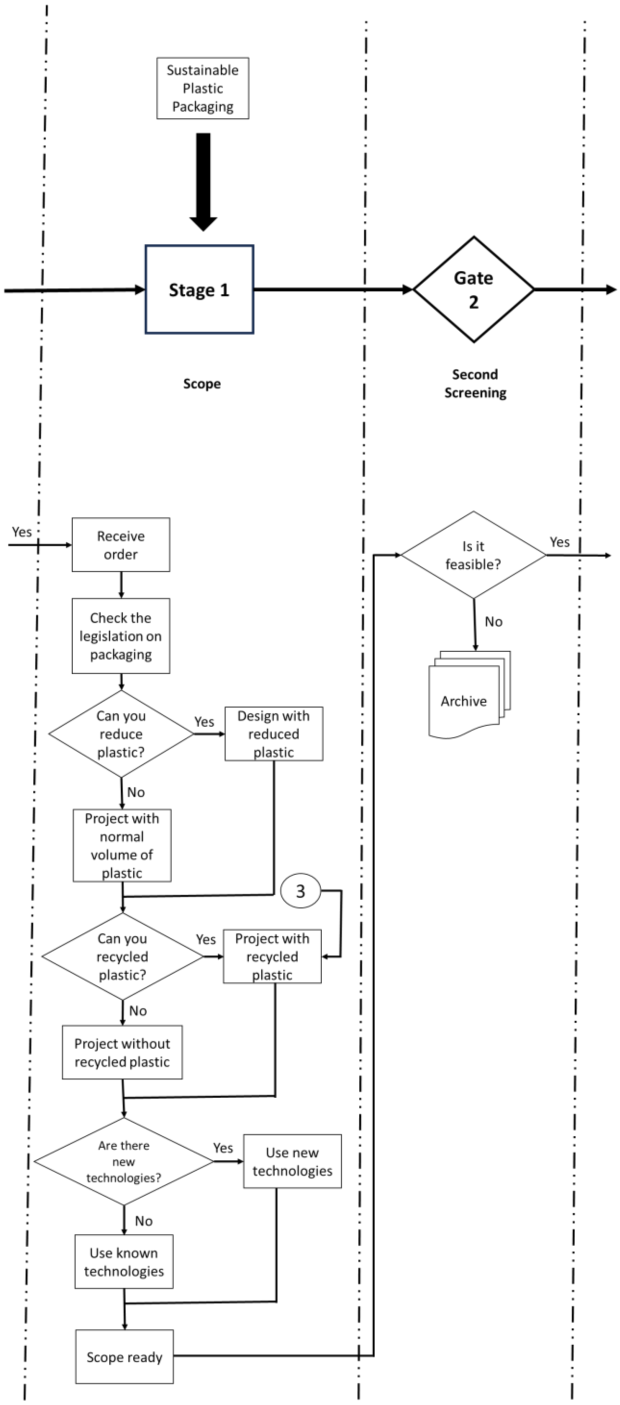

Figure 21: Activities of the scope stage
Source: prepared by the author

6.3 Stage 2: Business Plan

In the business plan stage, a detailed project describing how the packaging will be produced is developed. Considering the strategies and practices of CE, the business plan presented will focus on this subject.

One of the first activities is selecting the materials that will be used in the packaging. This choice must analyze performance, recyclability, and cost. It is also important to evaluate suppliers to ensure quality and consider environmental impacts throughout the life cycle. The use of recycled material must be evaluated with additional rigor to ensure that it can meet all needs and requirements.

Another activity is designing packaging with a smaller volume of plastic in order to reduce the use of virgin materials. Therefore, a design project with reduced thicknesses and optimized geometries must be defined, while ensuring that the packaging fulfills its function of storage, transportation, and consumer use.

Another practice is creating packaging that can be easily disassembled. Packaging components must therefore be designed so they can be separated without effort, facilitating recycling. For example, caps and labels that can be easily removed. In this way, the material recovery rate increases and contributes to the circular economy, which requires that materials remain in circulation for longer periods.

Depending on the type of packaging and its purpose, it may be designed for multiple uses, such as refill systems or returnable packaging. In this case, the design must prioritize durability, ease of cleaning, and resistance to repeated handling. This approach extends the packaging life cycle, reducing the need for new raw materials and reinforcing the circularity concept.

The packaging must be designed with a physical structure capable of ensuring mechanical resistance and fulfilling its function. This involves simulations of drop, compression, and stacking, as well as compatibility tests with filling lines. Poorly designed packaging may cause leaks, product losses, and rejection by consumers. Therefore, this design must consider not only aesthetics but also functionality throughout the entire logistics chain.

Labels, printing, and graphics must be developed correctly to ensure sustainability. An inadequate label may make the recycling of the entire packaging unfeasible. Therefore, compatible inks and adhesives must be used, along with options such as removable labels in recycling processes. In addition to the environmental aspect, the label design must also meet legal and marketing requirements, ensuring clarity of information and visual attractiveness.

Providing clear information about sustainability and the circular economy directly on the packaging is an increasingly valued practice. Disposal icons, refill instructions, or QR codes directing consumers to educational pages help users adopt proper practices. This communication should be simple, objective, and easy to understand so that consumers are not confused at the moment of disposal.

Another modern requirement is packaging traceability. This means enabling the identification of batches, manufacturing dates, and even reuse cycles. Technologies such as QR codes, barcodes, or markers may be used. The Internet of Things and artificial intelligence are two technologies that are being widely studied and used and may also support the traceability process. Traceability is important for quality control and for circularity and sustainability indicators.

Once the business plan is completed, the project goes through an approval committee (Gate 3). The committee may be composed of managers and leaders from strategic areas, including representatives from the following departments: executive board, marketing, engineering, production, quality, and finance. If failures are identified, the project is reviewed and returned to the previous stage for adjustments in order to avoid rework. If approved, the physical development of the packaging begins.

Figure 22 presents the sequence of activities in the business plan stage.

6.4 Stage 3: Development

At this stage, the packaging begins to be developed and the business plan is put into practice. Each part of the packaging is developed, such as the body, cap, and label, all with detailed technical production specifications. Pilot tests, engineering adjustments, and preliminary validations are carried out. The production line executes the process according to the planning established for manufacturing.

The final label (which may also be understood as printing and graphics) is developed at this stage, with marketing approval, while also considering legal aspects. Layout, colors, adhesives, and finishes are defined. The label must comply with all legal requirements, convey the brand’s visual identity, and at the same time not compromise the recyclability of the packaging. Primary tests of printing and adhesion must be carried out to validate the selected material.

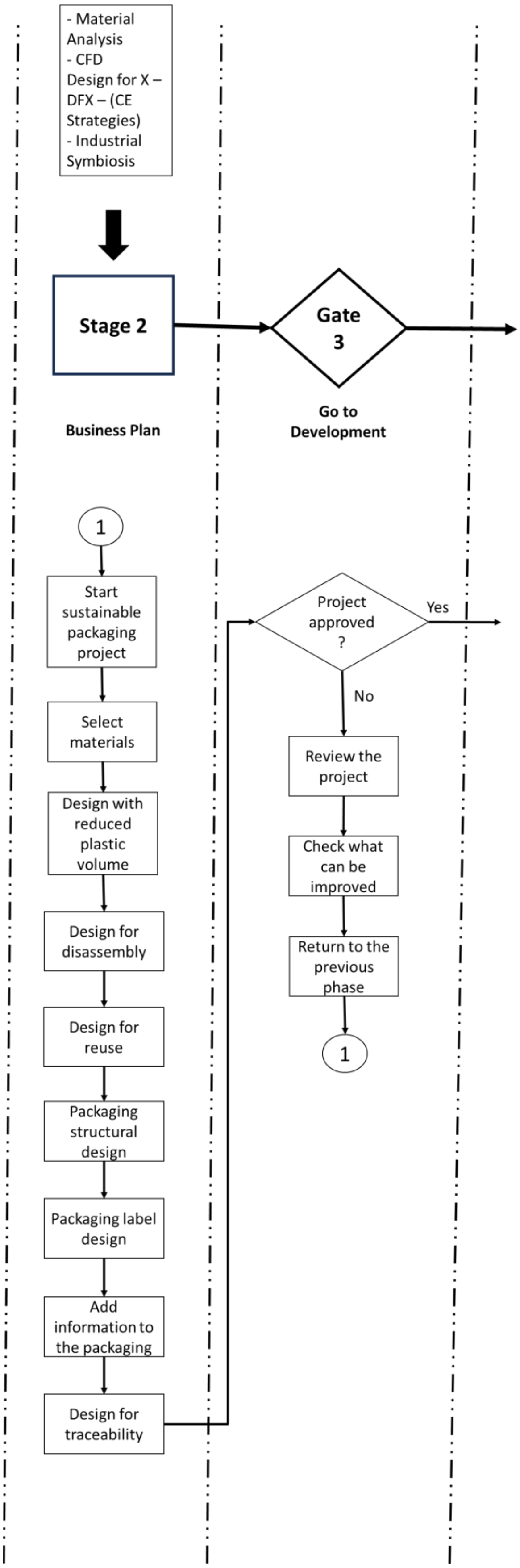

Figure 22: Activities of the business plan stage
Source: prepared by the author

Information related to the circular economy and how it will be incorporated into the packaging design must also be developed. This may include disposal instructions, guidance on refill programs, or icons indicating that the material is recyclable. These elements strengthen the brand image and encourage more sustainable practices by consumers.

It is also at this stage that batch marking and traceability systems are defined. Codes are defined and registered for each packaging unit. Packaging then receives unique codes that allow the identification of its origin and trajectory. Through this system, the company can address both failure-related aspects and track when its packaging is passing through recycling or reuse systems.

Before initiating the testing stage, it is verified whether all development requirements have been fulfilled (Gate 4). If there are failures or pending issues, the project returns for rework. If everything is complete, it advances to the validation phase.

Figure 23 presents the sequence of activities in the development stage.

6.5 Stage 4: Testing and Validation

At this stage, the packaging undergoes several tests to verify whether it was produced correctly and meets all the project requirements. The first type of test is quality testing, which verifies whether the packaging meets the established standards, such as dimensions, visual appearance, and functionality. These tests aim to ensure that the packaging complies with the technical specifications requested by the client.

Another type of test performed is robustness testing, in which the packaging is evaluated through tests such as drop, compression, and stacking. The purpose of these tests is to simulate real transportation and storage conditions to ensure that the product reaches the final consumer intact.

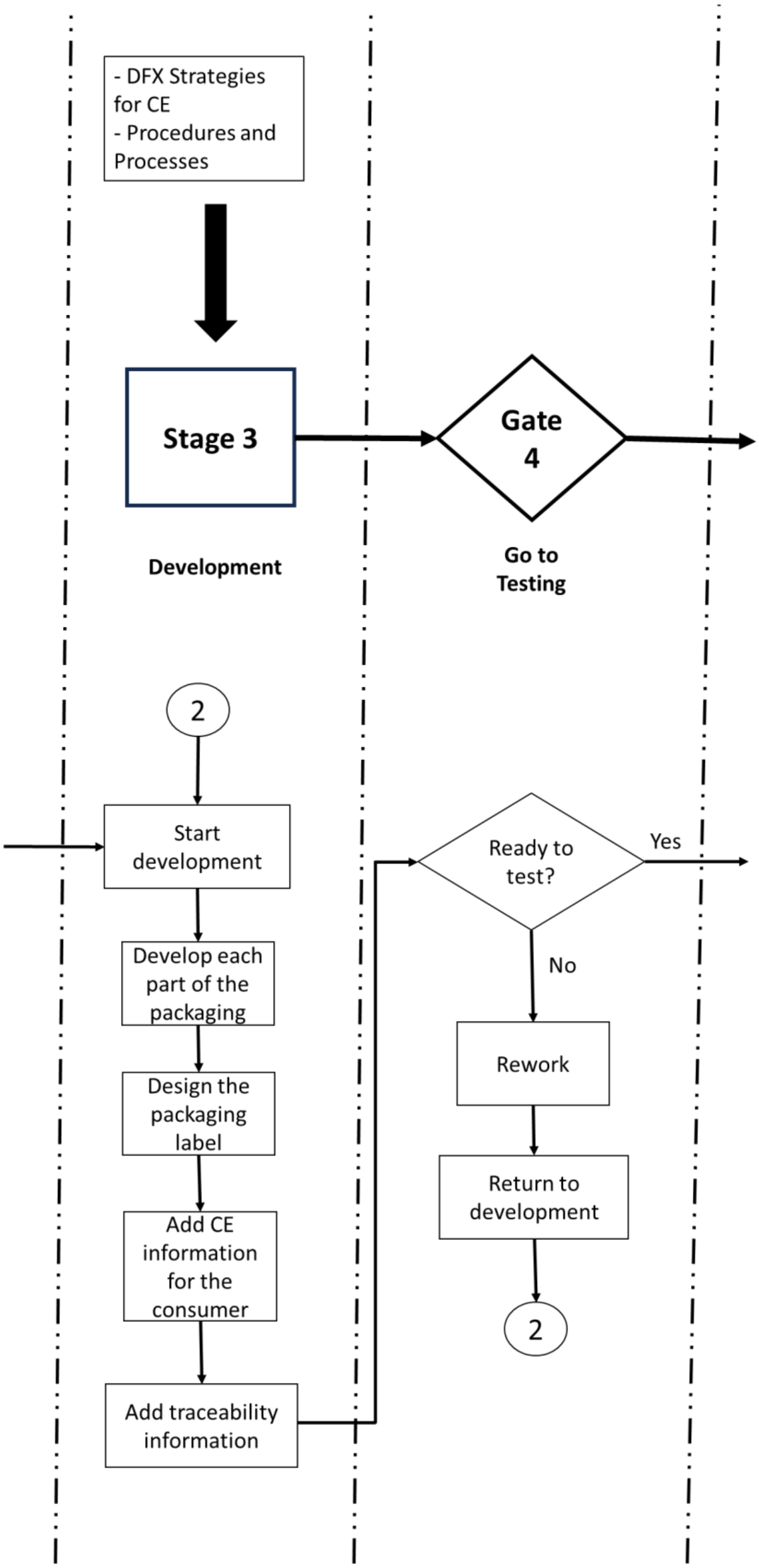

Figure 23: Activities of the development stage
Source: prepared by the author

Performance tests are also conducted to evaluate the functionality of the packaging during use. For example, it may be verified whether the liquid flows correctly, whether the cap seals properly, or whether the dosing system works as planned. These tests ensure the consumer experience.

Disassembly testing is conducted with the recycling process of the packaging in mind, in order to ensure CE principles and practices. In this context, components must be separated without effort or with minimal effort and without compromising the recyclability of the materials. The simpler the disassembly process, the higher the recycling rate.

In the case of packaging designed for multiple cycles, it must be tested through trials that simulate repeated use. Mechanical resistance, chemical stability, and the possibility of cleaning are verified, for example. The purpose is to ensure that the packaging can withstand several life cycles without compromising safety or functionality.

After the testing stage, the project is submitted to a new decision point. If any failure is identified in the packaging, it must return to the development stage for rework. If it complies with all requirements, the packaging is approved for market launch.

Ideally, depending on the type of packaging, the company should seek the standards that specify the tests to be carried out, as well as the criteria and specifications to be achieved.

Figure 24 presents the sequence of activities of the testing and validation stage.

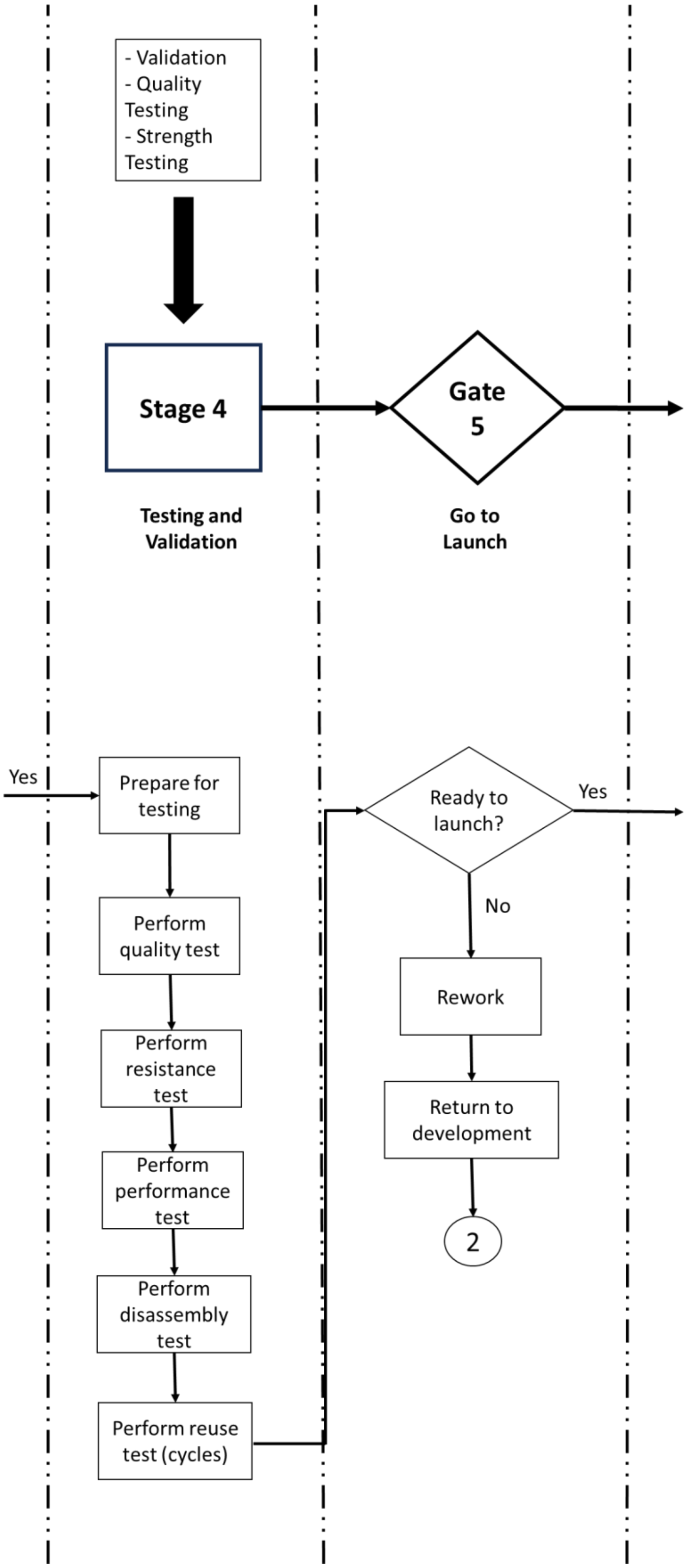

Figure 24: Activities of the testing and validation stage
Source: prepared by the author

6.6 Launch

In the launch phase, the packaging is ready to be delivered to the client. Therefore, it is necessary to consider some sustainability and CE actions. Examples include reverse logistics programs, collection points in partnership with retailers, reuse systems such as refill packaging for multiple cycles, and the creation of circularity indicators. The purpose is to evaluate the environmental impact of the project and ensure that CE practices and strategies are implemented.

The first activity at this stage is the verification of the finished packaging. It has already been produced and tested, but it is necessary to verify the client’s order to determine the quantity to be produced.

The next step is the delivery of the packaging to the client. The logistics department or responsible sector must ensure that the correct quantity is delivered within the agreed timeframe. It is also important for the sales and commercial teams to find ways to collect customer feedback to confirm whether all specifications were met and whether improvements are needed for future production.

An important point to consider is reverse logistics, which in Brazil is established by the National Solid Waste Policy (PNRS). Therefore, the company must develop mechanisms to ensure that packaging, after consumption, returns to the production cycle. This can be done through collection points for sending packaging to recycling facilities or back to the production process, aiming at reuse systems. Reverse logistics helps reduce improper disposal and increase recycling, reinforcing the principles and practices of CE.

Collection points may belong to the company itself or to partner organizations, which may include the clients who purchased the packaging or waste picker cooperatives. It is also important to create campaigns encouraging end consumers to return packaging to collection points. This can be done through marketing initiatives and information included on labels, prints, or directly on the packaging body.

In addition to collection points, reuse programs can be implemented through refill packaging that can be used across several cycles. Returnable packaging can be reused multiple times before disposal. This initiative significantly reduces the need to produce new packaging and encourages CE practices that aim to keep materials and components in circulation for as long as possible.

Once these strategies have been established, it becomes necessary to measure their performance, which can be done through circularity indicators. Examples of indicators that may be used include recycling rate, material recyclability, reuse rate, durability, and reparability. Measuring these data and creating such indicators supports sustainability and CE reports, as well as consumer awareness campaigns.

After the launch stage is completed, the company must focus on the post-sales phase. It is important to monitor the destination of the packaging to ensure that CE practices and strategies are functioning correctly.

Figure 25 presents the sequence of activities in the launch stage.

6.7 Post-Launch Review

After the launch, the post-launch review stage begins, which evaluates the destination and use of the packaging. However, the focus here is based on CE, since it is necessary to carry out certain activities so that CE practices and strategies can be effectively evaluated.

Regarding recycling, the company must decide whether it will carry out the recycling process itself or establish partnerships with other companies that perform this service. If the company decides to handle it internally, it must begin collecting the packaging (this can be done through the collection points already defined in the previous stage) and send it to the appropriate department (or partner) responsible for performing the recycling process. The plastic may then be recycled and used in the production process of new packaging or directed to other processes that use plastics, if the company has partnerships for this purpose.

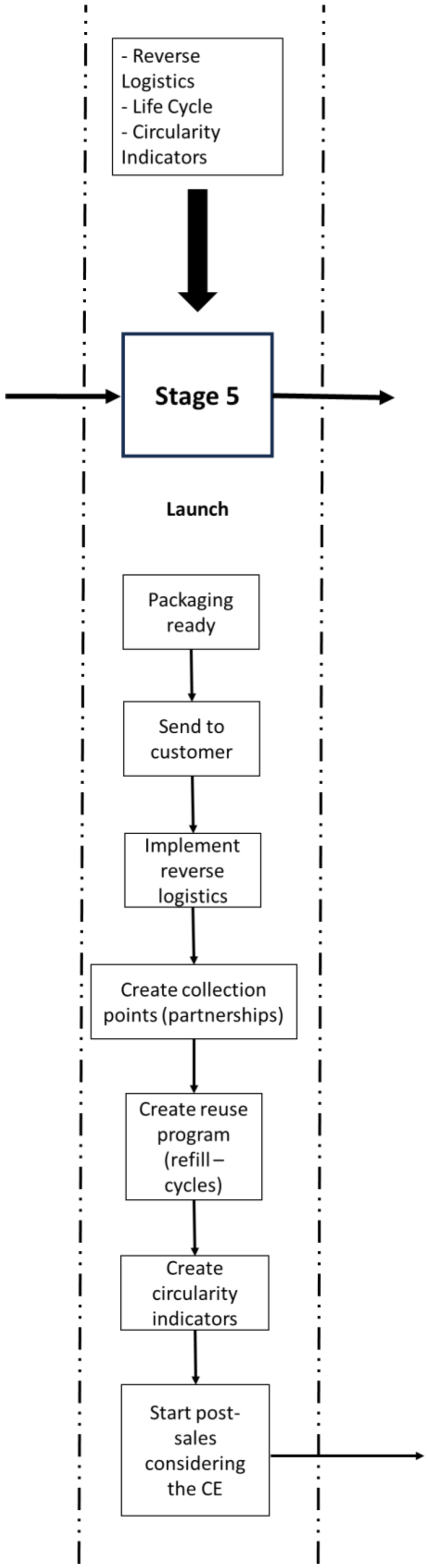

Figure 25: Activities of the launch stage
Source: prepared by the author

Another option is to seek partnerships for recycling, which may include recycling companies or waste picker cooperatives. These organizations may also provide packaging collection services directly from consumers or receive packaging from the collection points defined by the company. After the plastic is recycled, it can return to the company's production process, which requires the establishment of logistics to collect the recycled plastic. All steps must be clearly defined to implement the recycling strategy according to CE principles.

Another aspect that must be analyzed at this stage is the reuse program. The company needs to collect the packaging that will be reused, which can be done through the collection points and also requires information from consumers so that refill packaging can be reprocessed. A strong consumer education campaign is important to ensure that this program functions properly and that packaging can be used for several cycles.

Figure 26 presents the sequence of activities in the post-launch review stage.

6.8 Verification of the model's adequacy

To verify the adequacy of the model, it was sent and presented to the individuals from the two companies who had answered the questions in the case study. These respondents, specialists in the subject, were interviewed again to verify the adherence of the model to the processes of Companies A and B.

For each stage (1 to 5), three questions were asked:

1. For Stage 1, do you agree with the activities proposed for the scope of the packaging development process?
2. Is there any activity in Stage 1 that you consider inadequate in relation to the process carried out by the company?
3. Is there any activity in Stage 1 that you believe should be included in order to make it consistent with the process carried out by the company?

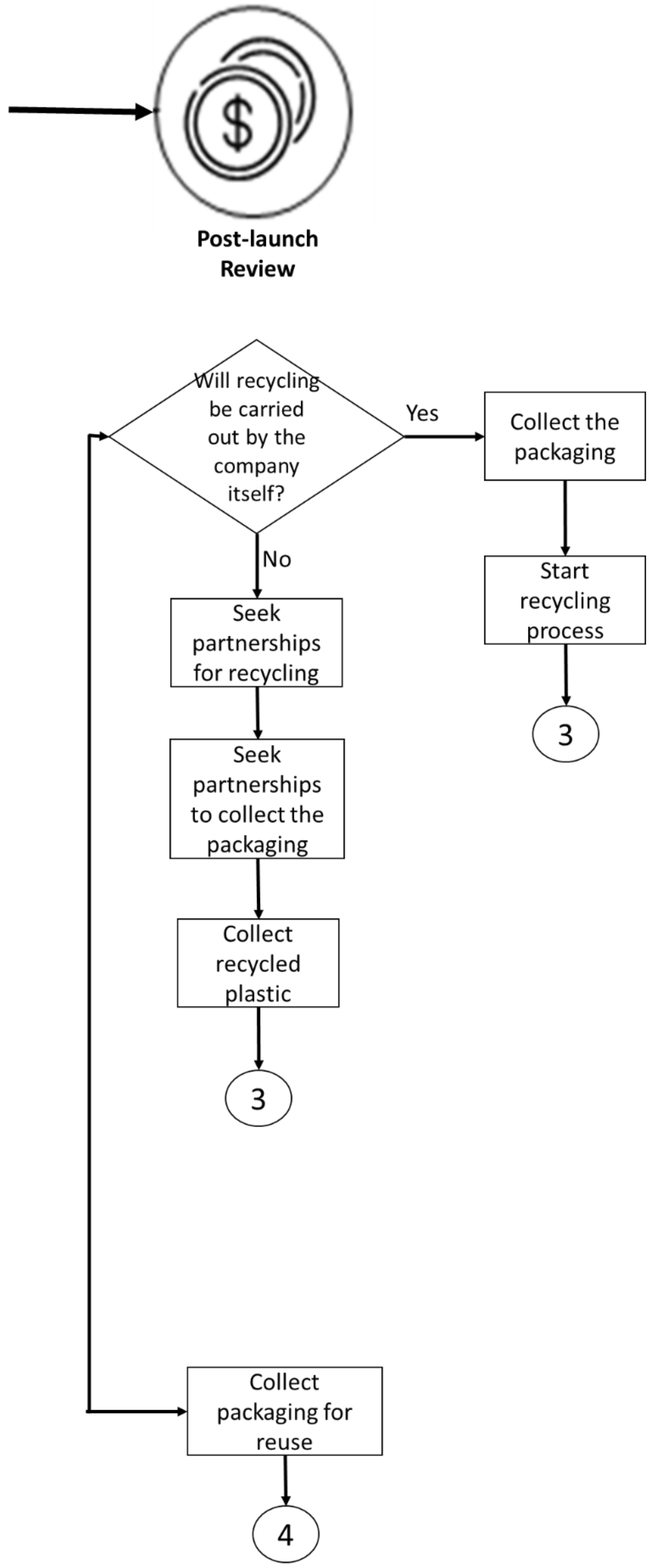

Figure 26: Activities of the post-launch review stage
Source: prepared by the author

Questions were also prepared regarding the gates:

1. Are the actions described for each gate correct and appropriate to the reality of the packaging development process?
2. Is the number of gates established appropriate?
3. Do the final activities of each gate return to appropriate activities within the stage flow?

6.9 Analysis of the responses for model adequacy

6.9.1 Responses for Stage 1

In general, regarding the first question, Companies A and B agree that the activities of Stage 1 represent an initial phase dedicated to a broad analysis of the project's possibilities, without detailed technical deepening, but with the need to visualize the overall context before advancing to the next stages.

Analyzing both responses, both Company A and Company B highlight the importance of sustainability, whether by proposing more responsible alternatives to clients or by evaluating recyclable materials, plastic reduction, and practices aligned with the circular economy.

Despite these convergences, the two companies differ in how they structure their perspective on the process. Company A presents a more relational perspective, emphasizing the role of the client and the dynamics of interaction between client and supplier. The response describes how different client profiles influence development, highlighting that more open clients allow greater freedom to propose sustainable solutions, while more restrictive clients require strict adherence to their specifications.

Company B, in turn, adopts a more technical and normative approach. The company focuses on verifying technical and regulatory feasibility, especially related to food-contact standards and environmental legislation. In addition, it emphasizes the analysis of material technologies, such as monomaterial structures, barrier films, and sealing optimization, always seeking to balance performance, cost, and environmental responsibility.

Thus, while Company A prioritizes the client relationship and adaptation to different demand profiles, Company B emphasizes technical, regulatory, and technological criteria. Both converge on the importance of sustainability and the need for a comprehensive initial assessment, but they clearly differ in their focus and adopted approach.

When analyzing the responses from the two companies regarding the second question, it was verified that both companies agree that the activities proposed for this stage are relevant and well aligned with the objective of establishing general project guidelines. Both companies also demonstrate concern with technical and regulatory compliance, indicating that the evaluation of standards and legal requirements is essential from the beginning. Another common point is attention to sustainability, either through the analysis of recycled materials, as in the case of Company A, or through the pursuit of technical efficiency and environmental adequacy, as reflected in the more direct practices of Company B.

Despite these points of convergence, the differences between the responses are quite significant. Company A presents a more technical and detailed approach. It suggests specific adjustments to the thesis text (which were subsequently incorporated according to the response) and describes in depth the types of recycled materials available and the criteria required for their use. This company highlights the importance of evaluating raw material availability, quality, legislation, compatibility, and the need for preliminary tests, indicating a robust and highly technical process.

Company B, on the other hand, adopts a more simplified and practical perspective. It explains that, since it mainly serves small and medium-sized clients, its projects have lower technical complexity and shorter deadlines. For this reason, several analyses are carried out directly, based on the team's already consolidated knowledge, without requiring formal research or validation structures. Its focus is on agility, competitive cost, and adapting the process to the reality of its clients and the scale of the projects.

In summary, Company A operates with greater technical depth and detailed criteria, while Company B focuses on efficiency and simplification. Even following different paths, both recognize the importance of Stage 1 and sustainability as essential elements in packaging development.

Analyzing the responses provided by the two companies regarding the third question, it can be observed that Company A states that the activities already included are adequate, indicating only the need to revise the items previously mentioned in the first two questions. Therefore, it does not suggest the inclusion of new stages in the process, demonstrating adherence between the current model and its operational practice.

On the other hand, Company B presents a different perspective by identifying the need to expand the scope of Stage 1. The company argues that the process should incorporate activities related to commercial analysis and economic feasibility evaluation, which precede the technical definition of the packaging (activities that this company already performs). It also highlights the importance of reviewing the client’s history, particularly in recurring cases, as a way to optimize time, standardize solutions, and reuse previously validated structures. In addition, it emphasizes the relevance of an initial validation with the client regarding the final application of the packaging, including understanding the characteristics of the product, the filling process, storage conditions, and exposure environment, factors that directly influence the choice of the most appropriate packaging structure.

A common point between the responses is the concern with the accuracy and adequacy of the information present in the initial stages of the process, although this concern manifests itself differently in each company. However, a central divergence becomes evident: while Company A considers the current process sufficient, Company B believes that Stage 1 should be enriched with additional commercial, operational, and technical analyses, reflecting a model of operation more integrated with the needs and profiles of its clients. This difference indicates significant variations in working methods and in the level of complexity of the activities carried out by each organization.

Therefore, the suggestion presented by Company B regarding the inclusion of the review of the client’s history will be incorporated into the proposed model, as it contributes to process optimization and increases the precision of the initial project definitions. Considering information from previous orders enables greater agility in the development of solutions, promotes technical and visual standardization, and facilitates the reuse of previously validated structures, elements that strengthen operational efficiency and coherence in packaging development.

With these three questions, the evaluation of the adequacy of Stage 1 of the model, corresponding to the discovery and scope phase, was completed. The next three questions will be related to Stage 2, which corresponds to the business plan.

6.9.2 Responses for Stage 2

The analysis of the responses provided by the companies regarding the first question reveals a general consensus about the adequacy of the activities proposed for Stage 2 of the packaging development process, although there are relevant differences in the way each organization structures and executes this stage. Company A provided a more concise and direct response, simply stating that it agrees with the activities presented and that they are consistent with this stage of the model. Company B, in turn, also expresses agreement with the proposed set of activities, recognizing that it appropriately represents the moment when the project gains greater concreteness and begins to articulate technical definitions with production and commercial feasibility. In addition, the company highlights that aspects such as material selection, the pursuit of plastic volume reduction, and the encouragement of design for disassembly or reuse are aligned with the sustainable practices that guide its operations.

Another point that deserves attention is that Company B clarifies that, in its operational reality, Stage 2 assumes a less formal and more pragmatic character. This company works with short-cycle projects and moderate levels of customization, which leads to decision-making mainly based on accumulated technical experience and on the history of solutions applied to clients with similar characteristics.

Thus, although both companies agree with the general guidelines of the stage, Company B explains how it adapts its execution to ensure greater agility and adherence to the profile of the market in which it operates, highlighting differences in the practical operationalization of the model.

Based on the responses provided by the companies regarding the second question, it is possible to observe distinct perceptions about the adequacy of the activities proposed for Stage 2.

Company A presented considerations regarding the text that explains each activity in the model. Its observations focus mainly on the need for greater terminological uniformity (such as the use of acronyms, which was corrected) and greater generalization to encompass all types of packaging. In this sense, the sections referring to labels were expanded in the text to better explain the content. In addition, Company A recommends strengthening the discussion about emerging technologies, such as the Internet of Things and Artificial Intelligence, emphasizing their relevance for traceability, quality control, and circularity indicators (this section was also revised). Thus, Company A does not question the relevance of the activities but suggests adjustments to ensure greater clarity, technical precision, and alignment with contemporary practices in the sector.

Company B, on the other hand, recognizes that the proposed activities are conceptually correct but emphasizes that some steps present a level of complexity greater than what is necessary for its operational reality. Since it mainly serves medium and small clients, the company states that in-depth analyses of design for disassembly or formal business plan studies do not fully apply to its workflow. In its daily practice, a simplified and objective approach prevails, focused on immediate technical feasibility, material costs, and adaptation of the project to the available production resources. Therefore, although it agrees with the general concept of Stage 2, Company B performs a leaner and more dynamic execution, adapted to the agility required by its market.

As a common point between the companies, it is observed that both recognize the relevance of the proposed activities and do not consider them inadequate in their essence. However, they differ regarding the level of detail, formalization, and scope required. Company A suggests technical and conceptual improvements to refine the content, while Company B identifies the need to simplify certain stages in order to adapt them to a more agile and less complex operational context. These differences reflect the structural and strategic particularities of each organization.

The analysis of the responses regarding the third question highlights significant differences in the way the companies approached the issue of potentially including new activities in Stage 2 of the proposed model.

Company A provided a direct and objective response, stating that it does not identify any gaps and that the stage is adequate for its process, without suggesting additional elements.

In contrast, Company B provided a more extensive response, describing internal practices adopted in its operational workflow, which mainly reflect its daily dynamics rather than potential deficiencies in the proposed model. Among the points mentioned, the company refers to technical production validation, consultation of performance history, and simplified economic verification.

However, these activities represent practices widely disseminated in processes that use structured models such as Stage-Gate and are therefore implicitly included in the logic of this type of methodology.

With this third question, the analysis of Stage 2—the business plan stage—is concluded, allowing the discussion to proceed to the questions related to Stage 3, which corresponds to development.

6.9.3 Responses for Stage 3

The responses provided by the companies to the first question regarding the adequacy of the activities proposed for Stage 3 of the packaging development process reveal both points of convergence and divergence, as well as differences in the form of argumentation and in the degree of reference to their own internal processes.

In general, both companies recognize that the proposed activities are appropriate for the packaging development phase, demonstrating consensus regarding the overall scope of this stage. This agreement appears explicitly and directly in both responses, although with different emphases.

Company A provides a more direct, brief response focused on the adequacy of the wording. The company criticizes the recurrence of references to labels, suggesting greater terminological generality to avoid restricting the model to a single type of packaging. In this sense, the section discussing labels was rewritten to improve clarity. In addition, the company recommends adjustments to the formulation of certain passages, pointing out the need to employ broader expressions. In this part, the text was improved in order to clarify when a statement refers to an example and when it addresses a general issue. Its analysis focuses predominantly on the form of the text, emphasizing precision and conceptual breadth.

Company B, in turn, provides a more extensive and descriptive response, referring in detail to the development process adopted internally. The company highlights the practical importance of the stage, describing routine activities such as the preparation of pilot samples, sealing tests, resistance verification, and evaluation of the final appearance, as well as aspects related to material compatibility. Although it does not propose modifications to the text of the presented model, it uses its practical experience to justify its agreement and to reinforce the coherence of the listed activities with the requirements of flexible packaging production.

In summary, while both companies validate the activities of Stage 3, Company A concentrates its contribution on improving the wording and expanding the conceptual applicability, whereas Company B reinforces the practical adherence of the model through the description of its own production workflow.

The responses provided by the companies to the second question, concerning whether any activity in Stage 3 is considered inadequate for the process they carry out, reveal both convergence and divergence regarding the style and depth of the contributions.

Company A presents an extremely direct and concise response, simply stating that it does not identify any inadequacy in the proposed activities, thus offering a straightforward validation of the presented model.

Company B, on the other hand, provides a more extensive and analytical response, describing in detail how its internal process relates to the activities of the stage. Although it considers the set of activities appropriate, the company points out that some of them are more complex than necessary for its production reality. It explains that tests are usually performed directly in the industrial environment, which allows rapid results aligned with materials that are already consolidated and widely used. In addition, the company emphasizes that most of its clients are small and medium-sized enterprises that are already familiar with the materials employed, which reduces the need for formal laboratory protocols or more elaborate approval procedures. Thus, its analysis associates the adequacy of the model with its specific operational context, emphasizing agility, practicality, and reliability based on accumulated experience.

The common point between the two responses lies in the agreement regarding the overall relevance of the activities in Stage 3. Both confirm that there are no substantial inadequacies in the proposed scope.

The responses of the companies to the third question regarding the possible inclusion of new activities in Stage 3 of the packaging development model present different levels of detail and distinct perspectives regarding the practical application of the process.

Company A offers a brief and objective response, stating that it does not identify any additional activity that should be incorporated into the stage.

Company B, in turn, presents suggestions based on practices that are effectively carried out within its production process. The company highlights the importance of steps such as practical validation on the production line, maintenance of an internal performance history of materials, and commercial and technical confirmation with the client. These activities reflect how development occurs in its specific context and demonstrate strong alignment with its operational routine. Although these suggestions are relevant for the company's reality, they can be considered inherent to the adaptive logic of the Stage-Gate model, which allows each organization to incorporate additional practices according to its needs and internal workflows. Therefore, the proposed model, being general and applicable to different packaging production structures, does not necessarily require the incorporation of these specific steps, leaving companies free to make the adjustments appropriate to their own development dynamics.

With the analysis of these three questions, Stage 3 (development) can be considered adequate according to the responses of both companies. The next questions will therefore be related to Stage 4, which corresponds to Testing and Validation.

6.9.4 Responses for Stage 4

The two consulted companies presented their considerations regarding the adequacy of the activities proposed for Stage 4—testing and validation—of the packaging development model in response to the first question.

Company A provided a more concise response focused on the wording of the analyzed material, highlighting the need for a terminological adjustment to ensure greater textual precision and emphasizing that the description of the stage is clear and well organized. Accordingly, the text was corrected based on the observations presented by Company A.

In contrast, Company B provided a more detailed response, directly relating the presented content to its internally adopted practices and emphasizing that the stage includes essential activities for the final validation process, such as performance on the production line, quality control, and formal approval by the client.

Thus, it can be observed that both companies demonstrated alignment regarding the relevance of the stage, although each emphasized different aspects of the material: Company A focused on the clarity and adequacy of the text, while

Company B emphasized the correspondence between the proposed model and its operational reality.

Both consulted companies also presented their responses regarding the second question related to the adequacy of the activities included in Stage 4 (testing and validation) of the packaging development model. In general, the activities presented were considered appropriate.

Company A provided a brief and direct response, stating that it did not identify any inadequacies and offering no additional observations regarding the process.

Company B, on the other hand, provided a more extensive and contextualized response, describing how internal practices vary according to the size and profile of clients. The company highlighted that although the scope of the stage is appropriate, the degree of formality applied to the activities depends on the specific requirements of each project, which leads to operational adjustments that the company routinely performs.

Therefore, it can be observed that both companies recognize the overall adequacy of the proposed activities, but only Company B explicitly relates its evaluation to its internal process, presenting operational nuances and variations in application.

Both consulted companies also presented their responses regarding the existence of additional activities that could be included in Stage 4 (testing and validation) of the packaging development model, in response to the third question. The analysis of the responses shows that both consider the stage to be adequate.

Company A offered a brief and objective response, stating that it does not identify the need for additional activities and without establishing a direct relationship with internal practices or with the conceptual structure of the model.

Company B, in turn, presented a more extensive and articulated response, describing elements of its own process that could be incorporated into the stage, such as internal approval records, final alignment between technical and commercial areas, and periodic review of approved materials. These suggestions correspond to procedures widely recognized in the literature and are consistent with principles characteristic of the Stage-Gate model, particularly with regard to the systematic recording of decisions, structured information flows, and post-approval monitoring.

Thus, it can be concluded that both companies maintain the perception that the stage is essentially adequate, although only Company B explicitly identifies opportunities for improvement which, in their nature, reinforce practices inherent to the Stage-Gate model itself. Since the proposed model is general, each company must adapt it according to its own operational reality.

With the analysis of these three questions, the validation of the adequacy of the activities in Stage 4 (testing and validation) is concluded. The next questions will be related to Stage 5 (launch) and to the post-launch review stage.

6.9.5 Responses for Stage 5

The two consulted companies provided responses to the first question regarding the adequacy of the activities proposed for Stage 5 of the packaging development process. In general, both recognize the importance of the activities planned for the post-implementation stage, highlighting the relevance of monitoring packaging performance after its introduction into the market.

Company B provides a direct, concise response that is fully aligned with the proposed scope, describing consolidated internal practices that converge with the presented model. In contrast, Company A offers a more detailed but less objective response, focusing mainly on critiques and suggestions related to the wording of the explanatory text of the model, which indicates greater attention to style and precision in the descriptions provided. These suggestions from Company A were implemented in order to improve the clarity and quality of the text.

Regarding the content, both companies mention aspects related to customer relationships, although from different perspectives. Company B reports that it systematically uses feedback from clients and sales teams as a tool for monitoring and continuous improvement, integrating this feedback into its internal processes. Company A, on the other hand, emphasizes that in its experience clients rarely provide proactive feedback, usually contacting the company only in situations where problems occur. As a result, the company attributes to the supplier the responsibility for proposing improvements. Thus, there is convergence regarding the relevance of post-launch monitoring, but divergence regarding practical experience and the adequacy of the wording used in the explanatory material presented to the companies.

The two consulted companies also provided responses to the second question related to the adequacy of the activities proposed for Stage 5 of the packaging development model. Both companies agreed that the activities presented are appropriate for a packaging development model.

Company A provides an extremely direct and concise response, simply stating that it does not identify any inadequate activity, without further comments or explicit references to its internal process.

In contrast, Company B presents a more extensive and analytical response, describing in detail how its actual process is structured and to what extent it differs from the proposed model. Company B also notes that some of the proposed activities are more formal than its operation requires, emphasizing that its post-implementation monitoring is largely practical, agile, and based on informal interactions with clients, sales teams, and production staff.

While the first company responds in a strictly affirmative manner, the second contextualizes its evaluation, demonstrating concern with accuracy and representativeness of practices and illustrating how its own packaging development process operates.

The two consulted companies also presented responses to the third question regarding the possibility of including additional activities in Stage 5 of the packaging development model. The analysis of the responses reveals differences in terms of objectivity and depth of the observations.

Company A provides a direct and concise response, stating that the stage is complete, without presenting additional comments or establishing an explicit relationship with its internal process.

In contrast, Company B provides a more detailed and contextualized response, describing specific practices from its operational routine and suggesting activities that it considers relevant to strengthen post-implementation monitoring. Company B proposes actions such as structured feedback collection, analysis of recurrence of non-conformities, and the recording of lessons learned.

However, it is observed that these suggestions correspond to practices widely recognized within product development models and may be understood as elements inherent to traditional Stage-Gate approaches.

Considering that the presented model has a general character and that each organization is expected to adapt it according to its own operational particularities, it was decided not to incorporate these suggestions explicitly.

With the analysis of these three questions, the evaluation of Stage 5 and of all stages of the model is concluded. In this sense, the next questions will be related to the gates presented in the model, which will be analyzed together.

6.9.6 Responses for the gates

Both consulted companies provided responses to the first question, allowing a comparative analysis of their perceptions regarding the adherence of the gate activities included in the proposed packaging development model.

The response from Company A was direct and concise, focusing specifically on the wording used in the presented model. The company highlighted that, in order to faithfully reflect organizational practice, it is necessary to avoid linking the description to a specific type of packaging and instead use broader terminology, such as legal text, marketing text, and nutritional information. In addition, the company emphasized the importance of reducing abbreviations and acronyms and explicitly defining all technical terms. Thus, its contribution focused exclusively on terminological and textual adjustments to Stage 5, without referring to the functioning of its internal processes. Several suggestions for textual improvements were incorporated to make the content clearer.

Company B provided a longer, more detailed, and contextualized response, centered on the development process currently used within the organization. The company indicated that the actions described in the model are conceptually aligned with the actual workflow adopted, although in practice the level of formalization varies depending on the size of the client served. Projects for medium and small clients tend to occur in a more integrated and simplified manner, while projects developed for large clients require stricter controls, extensive documentation, and formal auditing procedures.

In summary, both companies agree on the general relevance of the activities proposed in the analyzed stage. However, they differ in the nature of their suggestions. Company A limits its recommendations to terminological adjustments to better represent the categories of information present in packaging, whereas Company B expands the discussion by relating the model to the procedural specificities of its production reality, indicating different levels of formalization depending on the client profile.

Both consulted companies also provided responses to the second question concerning the adequacy of the number of gates established in the packaging development model. In general, both companies considered the number of gates presented in the model to be appropriate.

Company A presented an extremely direct and concise response, simply stating that the number of gates is adequate.

Company B, in turn, offered a more extensive, structured, and descriptive response, articulated in more elaborate language and with explicit reference to the development process adopted by the company itself. The organization confirmed that the five stages are appropriate and consistent with the natural flow of packaging development, emphasizing that the model promotes clarity, control, and reduction of rework. However, the company also reported that, in practice, some phases tend to overlap or integrate in order to ensure greater agility when serving medium and small clients. Even so, it recognized the usefulness of the model as a reference, provided that it is applied with flexibility according to the complexity of the project and the client profile.

In summary, both companies agree on the adequacy of the number of gates. However, they differ in the level of detail and focus of their responses. Company A simply confirms the adequacy without additional comments, whereas Company B provides a more detailed analysis, relating the model to organizational practices and emphasizing the need for contextual adjustments in the application of the stages.

Both consulted companies also provided responses to the third question regarding the adequacy of the return of the final activities of each gate to the flow of stages in the packaging development model, and both agreed with the flow presented in the proposed model.

Company A provided a relatively direct response, although accompanied by a practical example illustrating the real functioning of its internal process. The company confirmed that activities return to appropriate stages, explaining that in most cases the flow moves back only one stage for adjustments and redesign. However, it reported that there are exceptional situations in which the process must be restarted from the beginning, as occurred in a recent project where additional tests revealed packaging performance problems. Thus, its response emphasizes the variability of the return flow, supported by the organization's practical experience.

Company B provided a more extensive, structured, and formal response, centered on the operational logic of the model and its compatibility with the process used internally. The company confirmed the coherence between the final activities of each gate and the beginning of subsequent stages, emphasizing that these transitions support development continuity and prevent failures through technical and commercial verification. The company also noted that, although the model is adequate, its internal process is more dynamic and less formal, with stages that may occur simultaneously, reflecting the need for flexibility to serve different client profiles. Even so, it reinforced that the proposed sequence is functional and consistent with organizational practice.

In summary, both companies agree that the final activities of the gates appropriately return to the stage flow.

With the analysis of the questions related to the gates, it was possible to conclude the entire validation process of the adequacy of the proposed model. Only one additional activity was incorporated into the discovery stage, namely the verification of the client's history when the process begins with a request from an existing client of the company. The final model can be seen in Figure 27.

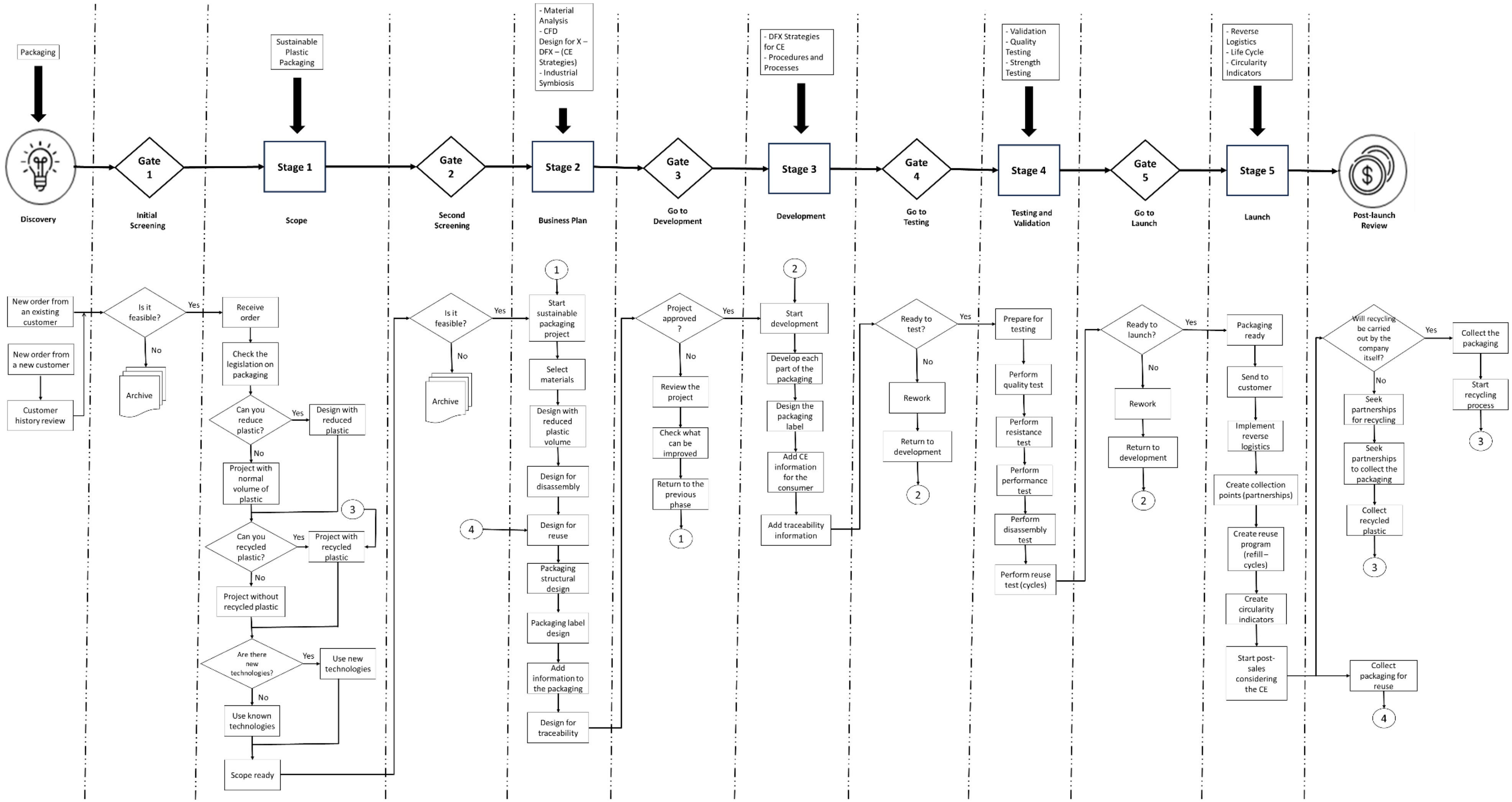

Figure 27: PDP model for plastic packaging considering CE practices
Source: prepared by the author

7. Final considerations

7.1 Conclusions

The transformation of production systems has become essential in light of the progressive depletion of natural resources and the increasing environmental impacts associated with the linear economic model. The linear logic, based on intensive extraction of raw materials, accelerated consumption, and immediate disposal, has proven incompatible with maintaining the regenerative capacity of ecosystems and the sustainability of production chains. In this context, the circular economy emerges as an approach that seeks to break this logic by proposing continuous cycles of use, reuse, and regeneration of materials, extending the value of resources over time and significantly reducing waste generation. This perspective is directly aligned with global sustainability commitments, including the Sustainable Development Goals, which emphasize the need for responsible production and consumption patterns, the adoption of environmentally appropriate practices, and the strengthening of partnerships that enable the transition to regenerative economic models.

Product development plays an essential role in this process, as it is at this stage that the fundamental characteristics determining the environmental performance of a product throughout its entire life cycle are defined. Different methodologies and models have been applied to guide this process, particularly those that structure decision-making in sequential stages and integrate technical, strategic, and operational dimensions. Despite their variations, these models converge on the need to organize the development flow in order to reduce uncertainty and increase the efficiency of new product conception. Historically, however, such models have been oriented toward economic feasibility and technical performance, dedicating little attention to circularity as a structural principle.

The incorporation of circularity into product development therefore becomes an essential condition for industrial sectors to operate responsibly and competitively. Product development must move beyond short-term technical and economic efficiency and begin to incorporate strategies that extend the value of materials throughout the product life cycle, reduce waste, and promote greater durability, reparability, and recyclability. This orientation requires that products be designed as circular from the outset, integrating circularity principles from the earliest stages of conception and planning.

The packaging sector occupies a central position in this discussion because it involves large production volumes, extremely short life cycles, and significant environmental impacts, especially considering the immediate loss of economic value after the first use. Low recovery rates and the rapid obsolescence of packaging highlight the need to restructure development models by incorporating more conscious material choices, design strategies that facilitate recycling, reuse alternatives, integration with reverse logistics systems, and mechanisms that allow materials to be reintegrated into renewed production cycles.

At the international level, the sector handles substantial production volumes and serves multiple supply chains, particularly in the food, hygiene, and consumer goods industries. In Brazil, the packaging sector occupies a strategic position in the national economy, both due to its industrial significance and the breadth of its activities. The country presents high consumption of plastic packaging, driven by the size of the consumer market and the expansion of retail. However, despite advances in recycling infrastructure and environmental awareness, plastic recovery rates remain below their potential. Moreover, a large proportion of discarded packaging does not return to the production cycle, highlighting the need to incorporate circular principles from the design stage. The relevance of this sector to the Brazilian economy reinforces the urgency of reassessing traditional practices and expanding strategies that promote greater material efficiency and reduced environmental impacts.

The adoption of the circular economy in the packaging sector therefore requires not only technological changes but also a cultural and organizational reconfiguration. It presupposes collaboration among suppliers, recyclers, certification bodies, clients, and regulatory institutions, consolidating networks capable of sustaining circular material flows at different scales. In this way, circularity ceases to be an isolated initiative and becomes a guiding principle capable of redefining production practices and strengthening the resilience of value chains.

In this context, it becomes essential to reposition product development as a central axis of circularity. It is in the early stages—when characteristics, materials, functionalities, and performance requirements are defined—that the circular potential of a package is established. The adoption of materials more compatible with recycling, structural simplification, the use of monomaterials, the planning of extended life cycles, and integration with reverse logistics systems depend on decisions made at the beginning of the process. For packaging to be circular, it is not sufficient to manage waste at the end of its life cycle; it must be conceived with this objective from the start. In the case of plastic packaging, this is particularly relevant, as early design choices determine its potential for reuse, recyclability, and reintegration into renewed production chains. When product development incorporates this perspective, it becomes possible to create packaging aligned with the principles of the circular economy, contributing to more sustainable and resilient production systems.

Therefore, the primary objective of this study was to propose and verify the suitability of a reference model for plastic packaging development, integrating Circular Economy principles, practices, and tools into the Product Development Process (PDP). To support this general objective, the following specific objectives were established:

- Analyze CE practices and incorporate them into the PDP;
- Analyze the tools to be used in the PDP that integrate CE practices;
- Verify the adequacy of the proposed reference model through the Case Study method.

The analysis of CE practices initially requires understanding their conceptual foundations, which define the circular economy as a model oriented toward reducing waste and enabling the continuous use of materials through reuse, recycling, and the regeneration of natural resources. It is also important to consider the principles of CE, such as the 3Rs (Reduce, Reuse, and Recycle), which support the model advocated by circular economy practices. This perspective reinforces that products must be born circular, meaning that circularity must be considered from the earliest phases of development. Circularity, however, is not limited to the choice of materials; it also involves principles such as life cycle extension, resource optimization, industrial symbiosis, reverse logistics, the use of indicators, and alignment with legislation. These elements are essential for reorienting product development in response to the challenge of keeping products, components, and materials at their highest utility and value for as long as possible.

Observing real practices allows for understanding how these principles manifest in the industrial sector, particularly in plastic packaging. One identified example is the development of packaging using certified recycled resin, reduced thickness, and solutions designed from the outset to be reintegrated into the production cycle, such as Ecoprime, a 100% recyclable shrink packaging solution. Other initiatives connect different actors in the supply chain to enable the return of materials, such as projects that collect packaging and transform it into PCR resin in partnership with cooperatives and clients. These practices reveal the central role of reverse logistics in enabling waste to return to the production process, while also highlighting benefits such as reduced use of virgin raw materials, strengthened recycling systems, and the promotion of new forms of cooperation. They also reveal barriers such as high costs, the need for appropriate technology, limitations in post-consumption recovery, and dependence on consumer engagement, as observed in the cases analyzed in Chapter 5 of this study.

Incorporating these practices into product development requires structured adjustments in the stages of the development process. This need becomes evident when observing that most PDP models focus on specific technical or managerial aspects and rarely incorporate circular economy principles as a central element for improving resource utilization. This highlights the importance of creating mechanisms that guide circularity from the earliest planning stages. Accordingly, specific activities were proposed to integrate circular practices into the development flow, including material analysis, recyclability assessment, design strategies that facilitate disassembly and reuse, and the adoption of tools such as life cycle assessment, industrial symbiosis, and reverse logistics. These activities aim to ensure that products are designed as circular systems in which components and materials remain in use for longer periods.

Thus, analyzing CE practices and incorporating them into the PDP means transforming theoretical principles into decision criteria, integrating practical evidence from industry, and reorganizing development so that circularity is not treated as a final step but as a structural requirement. This involves designing materials, functions, and disposal systems in an integrated manner, ensuring compatibility with recycling, the feasibility of reverse logistics, compliance with legal requirements, and alignment with circular performance indicators. By establishing these connections, it becomes possible to create products that effectively maintain value over time, reinforcing the transition toward more efficient, regenerative, and sustainable production systems.

The integration of CE tools into the PDP was structured through the adaptation of the Stage-Gate model, which served as the foundation for organizing the activities required for the conception, development, validation, and launch of packaging aligned with circular economy principles. This approach allowed the systematic distribution of tools across the PDP stages, ensuring conscious material selection, impact reduction, resource efficiency, traceability, and the closing of material loops.

In the initial stage, dedicated to scope definition, the model incorporates key decisions that guide circular development from the outset. These activities include verifying applicable legislation, assessing opportunities to reduce plastic volume, evaluating the feasibility of incorporating post-consumer recycled resin, and considering cleaner technologies. At this stage, the project's main circular objectives are defined, determining whether the packaging will prioritize plastic reduction, PCR incorporation, sustainable technologies, or alternative established solutions based on environmental criteria. Defining circular scope at this stage is essential because it influences all subsequent phases. Chapter 6 of this thesis presents the proposed model based on the Stage-Gate framework incorporating CE practices and tools for plastic packaging development.

As the process advances to the business plan stage, the PDP incorporates structured tools that deepen the technical and functional analysis of packaging from a circular perspective. These include material analysis to evaluate recyclability and compatibility with circular cycles; Circular Function Deployment (CFD), which connects packaging functions to circular economy strategies; Design for X techniques focused on recyclability, disassembly, reuse, modularity, and durability; and industrial symbiosis, which identifies opportunities for integrating processes so that waste from one stage can become input for another. Practical activities at this stage include selecting materials compatible with circular routes, designing packaging with reduced plastic volume, developing solutions that enable disassembly and reuse, and planning traceability and labeling information oriented toward the product life cycle. These activities are described in Section 6.3 of this thesis.

In the development stage, the tools planned earlier are applied directly to the product. Activities include detailing each packaging component according to circular economy guidelines, adjusting label and graphic design to facilitate recycling, including clear instructions for consumers regarding disposal and reuse, and implementing traceability systems through codes, markings, or technologies that enable monitoring of the post-consumption cycle. At this stage, circular design is effectively translated into technical specifications. These activities are described in Section 6.4 of this thesis.

The testing and validation stage consolidates the verification of circularity in practice. Quality, resistance, and performance tests are conducted, as well as specific disassembly tests that are fundamental for evaluating recyclability. For reusable solutions, durability and hygiene tests verify the packaging’s ability to withstand multiple usage cycles. These verifications ensure that the product conceived according to circular principles is technically viable, safe, and compatible with the recycling or reuse systems envisioned. These activities are described in Section 6.5 of this thesis.

Finally, the launch stage incorporates tools that ensure circular functionality in the post-consumption phase. These include reverse logistics mechanisms with structured collection and external partnerships, reuse programs encouraging return or refill, the creation of circularity indicators to monitor environmental performance, and post-sales monitoring oriented toward circularity. If the company does not perform recycling internally, the model includes the establishment of partnerships to ensure that circular flows are implemented. These activities close the loop, allowing packaging to return to the production system and providing data that feeds the PDP with real operational information about circular performance. These activities are described in Section 6.6 of this thesis.

By distributing CE tools and activities throughout all stages of the Stage-Gate model, the PDP becomes an integrated and sustainability-oriented process, ensuring that packaging is conceived, developed, tested, and launched in a way that allows it to remain in continuous cycles of use, recycling, or reuse. This consolidates circularity as a structural element of product development rather than merely an additional attribute introduced at the end of the process.

The verification of the adequacy of the proposed reference model was conducted through the systematic analysis of results obtained from the case study involving Companies A and B. The starting point for this verification was the recognition that the model needed to be refined based on evidence collected from the companies participating in the case study (as presented in Chapter 5 of this thesis). These adjustments were necessary to ensure that the model accurately represents the packaging development process. The refinements reflect the need to incorporate practices observed in industrial reality, aligning the model with the practical challenges faced by the analyzed companies.

The adequacy of the model is also supported by the observation that CE activities integrated into the PDP must reflect real corporate behavior, since the analysis revealed different levels of maturity and application of circular practices among the companies. The model was therefore adjusted considering routines, tools, and barriers identified in the study. This ensures that the theoretical proposal does not remain purely conceptual but represents a development flow compatible with industrial practice, while maintaining general applicability.

The validation process itself is discussed in Sections 6.8 and 6.9, which directly address the verification of the coherence and applicability of the model. In these sections, validation involves assessing whether the proposed stages and activities are applicable and sufficient to achieve CE objectives within the PDP. This validation considers not only the sequential structure of stages but also the relevance of the selected tools, the feasibility of the suggested activities, and their alignment with the needs of the packaging sector.

The validation of adequacy includes verifying the model's ability to guide decision-making at each stage of packaging development and assessing whether the defined activities effectively support the development of packaging according to CE principles. In this sense, validation does not merely describe the model but evaluates the practical effectiveness of the proposed activities, ensuring that each stage contributes to the circularity of the product.

Figure 27 presents the final model after all adjustments were incorporated in order to ensure coherence with the needs identified in the case study, demonstrating its adequacy. The verification confirms that the included activities are relevant, feasible, and aligned with both industrial practices and CE principles. Thus, the case study not only supports the construction of the model but also confirms its capacity to guide the circular development of plastic packaging, consolidating it as a consistent and applicable instrument for PDP.

Therefore, both the general objective and the specific objectives were achieved in the development and verification of the adequacy of the PDP model for plastic packaging that incorporates CE practices, demonstrating that a circular product must be conceived according to circularity principles from the beginning of its creation.

As a scientific contribution, this thesis proposes a reference model that integrates Circular Economy principles into the Product Development Process (PDP) within the plastic packaging sector, structuring phases, gates, practices, tools, and decision criteria applicable to the industrial context. The model extends the literature by transforming circularity concepts into specific operational activities within the PDP, enabling their application from the early stages of development.

From a practical perspective, the model offers organizations a structured roadmap to incorporate circularity right from packaging conception, supporting decisions related to material selection, recyclability, mass reduction, the use of PCR, component compatibility, disassembly, reverse logistics, and post-launch monitoring.

7.2 Limitations and Future Research

Although this thesis achieved its proposed objectives, some limitations were identified that require further investigation. In this study, these limitations are presented as suggestions for future research because they fall outside the scope of the present work.

The first limitation concerns aspects of the circular economy that were not considered in the model, such as water use (an important resource that may become scarce) and energy use (which should preferably come from clean and renewable sources, such as solar energy). The model focused exclusively on product development, which, in the context of this study, was specifically related to packaging. Therefore, the first suggestion for future research is to incorporate considerations related to water and energy into the proposed model.

A second limitation refers to the use and comparison with additional ecodesign concepts that were not extensively addressed in this thesis. These concepts were not included in order to maintain the focus on circular economy principles and practices within the product development process. Consequently, another suggestion for future research would be to compare the proposed model with ecodesign concepts and potentially adapt the model to incorporate these approaches as well.

Another suggestion would be to expand the number of cases (including more companies) to validate the model, thereby creating metrics to quantify its suitability based on the companies' analyses.

Furthermore, the research was developed using two case studies conducted within Brazilian companies in the plastic packaging sector, which limits the generalizability of the results to other industrial contexts. Data collection was predominantly concentrated on professionals directly involved in product development, without transversally encompassing other organizational areas relevant to CE implementation, such as production, procurement, quality, logistics, and post-consumer operations. Therefore, it is suggested that future studies expand the diversity of participants and analyzed areas within organizations, enabling a more comprehensive view of the proposed model's application.

Another limitation refers to the absence of a longitudinal implementation of the model within the analyzed companies. Consequently, it was not possible to perform a comparative quantitative evaluation of organizational results before and after the application of the model, particularly regarding environmental, operational, and economic indicators associated with circularity. In this regard, future research is recommended to conduct practical applications and longitudinal monitoring of the model to assess its impacts over time.

It should also be highlighted that the research focused specifically on the plastic packaging sector, excluding other industrial segments or alternative packaging types. Thus, future works are suggested to investigate the application and adaptation of the model in different industrial sectors, allowing for the evaluation of its adherence within distinct production contexts.

Another opportunity for future research relates to applying the model in organizations with varying levels of CE maturity. The cases analyzed in this thesis exhibited relatively similar characteristics regarding the adoption of circular practices; thus, it is not possible to state how the model would behave in companies at early or advanced stages of CE maturity. Furthermore, the proposed model does not include specific mechanisms to measure or classify organizational CE maturity. Accordingly, future studies are recommended to investigate potential adaptations of the model for different levels of organizational maturity and to develop assessment mechanisms associated with this context.

Finally, it is recommended to conduct studies focused on applying the model within small and medium-sized enterprises (SMEs), considering their structural, operational, and financial limitations. Future research can evaluate which practices, tools, and stages of the model present greater feasibility and contribution for smaller organizations, allowing for adaptations better suited to their characteristics and available resources.

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