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Designing Logistics Networks based on Sustainable Tertiary Transport Packaging Solutions under a Circular Economy

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Master in Management of Services and Technology

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The conclusion of my Master’s Thesis is definitely a remarkable moment in my life, as it also means the end of my academic journey. The last 5 years at Iscte, since I joined this university in 2015, were amazing in so many ways. I had the opportunity to meet people from many different places, make friendships, study abroad, learn from experienced Portuguese and foreign teachers and to develop in professional and personal aspects. Meanwhile, I enjoyed many networking moments both in and outside the campus of this university, which has a great academic spirit and where I concluded my Bachelor’s degree and will now conclude my Master’s degree.

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Resumo

A indústria das embalagens gera um impacto considerável na economia, ambiente e sociedade. Existe uma responsabilidade maior no que diz respeito ao seu efeito na sustentabilidade, uma questão cada vez mais preocupante nos últimos anos.

A pressão política e a perceção do consumidor estão a forçar a indústria das embalagens a adotar práticas sustentáveis tais como o uso de materiais alternativos sustentáveis. As embalagens dividem-se em primárias, secundárias e terciárias, sendo que as terciárias desempenham um papel importante no transporte, de forma a aumentar a eficiência logística das cadeias de abastecimento. Contudo, as embalagens terciárias de transporte geram desperdício excessivo. Posto isto, a Economia Circular surge como um modelo económico alternativo, onde a gestão da cadeia de abastecimento assume elevada relevância para implementar um design de rede logística que envolva Cadeias de Abastecimento de Circuito Fechado.

Esta Tese tem como objetivo conceber redes logísticas alternativas, baseadas em soluções sustentáveis de embalagens terciárias de transporte, num contexto de Economia Circular, enquanto contribui para a resolução prática do desafio de uma empresa.

Com base numa revisão de literatura, procede-se a uma sistematização de conhecimento em áreas importantes para analisar redes logísticas de fornecedores de embalagens, com práticas sustentáveis de circuito fechado que impactam o desempenho de sustentabilidade das suas cadeias de abastecimento. A melhor opção de material-fornecedor é selecionada para prosseguir com um estudo de caso onde diferentes cenários são assumidos.

Por fim, são apresentadas conclusões e soluções importantes para melhorar o desempenho da rede logística selecionada.

Palavras-chave: Sustentabilidade; Embalagens Terciárias de Transporte; Economia Circular; Gestão da Cadeia de Abastecimento; Design de Rede Logística; Cadeia de Abastecimento de Circuito Fechado.

Códigos de Classificação JEL: M11; Q01.

Abstract

The packaging industry has a considerable impact in the economy, environment and society. Along with its increasing importance, comes a high responsibility regarding its effect on sustainability, a growing matter of concern in the recent years.

Political pressure and consumer perceptions are pushing the packaging industry to adopt sustainable practices such as the use of alternative sustainable materials. Packaging is divided in primary, secondary and tertiary levels and tertiary packaging plays a major role in transportation processes to increase the logistics efficiency of supply chains. However, tertiary transport packaging is generating excessive waste. For reasons like this, the Circular Economy emerges as an alternative economic model, in which Supply Chain Management assumes high relevance for implementing a logistics network design that entails Closed-Loop Supply Chains.

This Thesis has the objective of designing alternative logistics networks, based on sustainable tertiary transport packaging solutions, under a context of Circular Economy, meanwhile contributing for the practical solution of a company's business challenge.

Based on a literature review, insights on important areas are systematized to proceed with an analyzis of packaging suppliers' logistics networks with sustainable closed-loop practices that impact sustainability performance of their supply chains. The best material-supplier option is selected to proceed with a case study where different scenarios are assumed.

Finally, important conclusions and solutions are presented to improve the performance of the selected logistics network.

Keywords: Sustainability; Tertiary Transport Packaging; Circular Economy; Supply Chain Management; Logistics Network Design; Closed-Loop Supply Chain.

JEL Classification Codes: M11; Q01.

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Glossary of Acronyms

CE – Circular Economy

CEO – Chief Executive Officer

CLSC – Closed-Loop Supply Chain

FL – Forward Logistics

HDPE – High-Density Polyethylene

KPIs – Key Performance Indicators

LE – Linear Economy

MCDA – Multi-Criteria Decision Analyzis

RL – Reverse Logistics

SCM – Supply Chain Management

SDGs – Sustainable Development Goals

SPC – Sustainable Packaging Coalition

SPSCM – Sustainable Packaging in Supply Chain Management

SSCM – Sustainable Supply Chain Management

UNEP – United Nations Environment Programme

USA – United States of America

WCED – World Commission on Environment and Development

1. Introduction

1.1. Theme Relevance

1.1.1. Packaging industry

Packaging plays a meaningful role in every aspect of people's current daily life and in the modern economy. Besides the basic protection feature, it also contributes to the proper transportation, storage and display of products, while enhancing the promotion of its value (Gutta et al., 2013).

Within the European Union, there is a context of political pressure as well as increasing consumer perception concerning sustainable packaging solutions, which has been developing along the years. Consequently, the strongest trends in the packaging industry in 2019 are entirely related to Circular Economy practices. Companies need to start using a system thinking approach and select packaging materials with the lowest production impacts, by comparing them based on the product unit required to safely package, according to different transport options and shelf-life periods (Kieselbach & D'Souza, 2019).

Following this reasoning, consumer tastes are increasingly shifting to greener packaging choices and there is a growing engagement of many different organizations to materialize the common intended transition to sustainable packaging approaches (FoodBev, 2018). Moreover, many countries decided to introduce bans and fees on the use of unsustainable packaging products (United Nations Environment Programme [UNEP], 2018).

Accordingly, the United Nations and the Ellen MacArthur Foundation (a charity organization created in 2010, that aims to accelerate the shift to a Circular Economy) started a movement named New Plastics Economy Global Commitment, which has been signed by more than 250 organizations at the beginning of the project. Among these, there are some of the biggest food and beverage companies, packaging manufacturers and also governments, united by the goal of eliminating plastic waste and pollution at its origin (Ellen MacArthur Foundation, 2019).

1.1.2. Sustainable packaging within the logistics and transportation market

Modern packaging solutions are essential to efficient logistics and retailing. According to García-Arca et al. (2014), the best packaging solution should simultaneously benefit from the most sustainable design with the minimum cost possible to be achieved.

Packaging is a key component in the logistics area, since it follows the product from the point of filling to its consumption stage. Accordingly, the integration of logistical and supply chain aspects into the packaging development process is likely to increase the economic and environmental performance of supply chains (Molina-Besch & Pålsson, 2014).

Packaging is divided in three levels, namely primary, secondary and tertiary. Tertiary packaging, used for bulk handling in warehousing and transportation within the logistics operations, is necessary for transportation in any production and distribution network because it has a considerable impact in the increase of logistics efficiency. Although, currently it produces a lot of packaging waste on a daily basis (Chung et al., 2018).

The packaging used to protect the product during its transportation process to manufacturers, distributors and retailers is called transport packaging. Transport packaging is a shipping unit which involves all industrial packaging, as well as the containers used for the shipment of consumer products. It provides the containment and protection to goods during the handling, storage and transportation processes.

Consumers are increasingly aware of the excessive waste created by transport packaging, mainly due to the growth of ecommerce and the associated packaging products delivered directly to their home (Sustainable Packaging Coalition [SPC], 2018).

1.1.3. Developing new packaging solutions using alternative sustainable materials

The choice of the packaging system will affect the economic and environmental performance of a supply chain (Pålsson et al., 2013). This is, among others, due to the fact that it directly impacts the energy use of transportation, handling and storage processes, influencing also the quantity of product waste generated within the supply chain (Molina-Besch & Pålsson, 2014).

Accordingly, crucial choices as raw materials selection and deciding between one-way or returnable packaging will directly influence waste management, as well as the whole logistics system (Pålsson et al., 2013). For these reasons, sustainable materials with responsible end-of-life treatments must be used in transport packaging solutions. Concerning the end-of-life view, reusable, recyclable and compostable materials are favorable solutions for transport packaging products. Regarding the sourcing perspective, materials from renewable sources and with recycled content will lead to sustainable packaging alternatives (SPC, 2018).

One of the main challenges and obstacles to environmental innovation of industrial transport packaging systems is the lack of cooperation between the different actors within the supply chain (Verghese & Lewis, 2007). Therefore, the identification of new sustainable practices should be an aspect to motivate for collaboration among the packaging supply chain players (SPC, 2018).

1.1.4. COMPANY A's challenge

This Thesis has the particular characteristic of aiming to reveal a practical application of sustainable packaging into a certain company's business context, which will be denominated as "COMPANY A" throughout this Dissertation.

COMPANY A is a start-up founded in 2018. Its mission is to transform waste into value, using state-of-the-art technology, through the empowerment of local people and providing cross-sectorial solutions worldwide. The company's challenge arises with the need for the constant sourcing of more and more sustainable ways of achieving its final products. Although focusing in plastic waste valorization for final product development is already a proper sustainable method, the company is approaching suppliers in the market to obtain other sustainable products, specifically concerning the transport packaging ones. For this reason, this project will contribute to fulfill that goal, namely by focusing on the economic and environmental sustainability and logistics performance evaluation of sustainable tertiary transport packaging products that could lead to the satisfaction of COMPANY A's clients' or partners' needs.

Not only the company aims to provide sustainable tertiary transport packaging solutions to its clients, but there is also a focus in another key aspect, which is the circularity of the products. Waste generated by transport packaging solutions should be avoided, although it is not possible to completely eliminate it. Therefore, there is the need for the design of logistics networks, based on the Circular Economy, that can promote an adequate end-of-life treatment for each of these products. This way, COMPANY A will be able to provide its clients with a clear and complete analyzis of the economic, environmental and logistics impacts of these solutions. Following this reasoning, this sustainable method will contribute to enhance the purpose of Circular Economy, that aims to break with the current linear take-make-use-dispose model that compromises the Earth's resources. Starting from the characteristics of the sourced products, which have to allow a sustainable end-of-life treatment and restarting the cycle again at the end of the product's lifetime, by avoiding product's complete disposal.

1.2. Research Problem

In the before mentioned context, there is an opportunity to conduct a research based on the development of a Dissertation.

Finally, the following research question arises, reflecting the research problem to be addressed:

How to design sustainable logistics networks based on the use of sustainable tertiary transport packaging within a Circular Economy context?

1.3. Objectives

The main objective of this project is to propose and evaluate alternative logistics networks based on the use of alternative sustainable tertiary transport packaging products within a Circular Economy context, while considering different economic and environmental sustainability indicators and logistics performance indicators.

In order to achieve this general objective, four specific objectives are set to be accomplished, in the following sequential order:

1. Identify and select suppliers of alternative sustainable tertiary packaging products that can be used for transportation and that fit within a Circular Economy context;

2. Design alternative logistics networks scenarios within a Circular Economy context, based on the use of the selected sustainable products identified as suitable for tertiary transport packaging;

3. Evaluate the proposed alternative logistics networks scenarios, in terms of economic, environmental and logistics impacts generated throughout the packaging products' entire life cycle (including the end-of-life treatment);

4. Present recommendations to the stakeholders involved in such logistics network context and to potential clients and partners that might be available to adopt a Circular Economy approach to increase the sustainability and logistics performance of their tertiary transport packaging solutions.

These objectives respond to the company's challenge of achieving more sustainable products with the lowest environmental and economic impact possible, not disregarding the logistics performance and the satisfaction of its clients' needs. As a result, the general and specific objectives should be considered to be achieved and furtherly practically applied to COMPANY A's context, through the evaluation of the sustainability of the logistics networks in a perspective of COMPANY A as the buying party.

1.4. Methodology Resume

Regarding the methodology to be implemented, this Thesis will follow the guidelines of a *case study*. According to Yin (1994), there are 3 conditions that must be evaluated to conclude the most appropriate research method to apply:

1. The type of research question;
2. The extent of control and influence that a researcher has over actual behavioral events;
3. The degree of focus on contemporary events, instead of on historical ones.

Table 1.1 – Relevant situations for different research methods (Yin, 1994)

Research Method	1. Form of Research Question	2. Requires Control of Behavioral Events?	3. Focuses on Contemporary Events?
Experiment	how, why?	yes	yes
Survey	who, what, where, how many, how much?	no	yes
Archival Analyzis	who, what, where, how many, how much?	no	yes/ no

History	how, why?	no	no
Case Study	how, why?	no	yes

As outlined in Table 1.1, the case study research method poses a research question in the form of “how?” and “why?”, the researcher does not have control of behavioral events and it is focused on contemporary events. As stated in section 1.2., this Thesis presents a research question in the form of “how?”. Moreover, it does not require the researcher to control or influence behavioral events and it will focus on contemporary events.

It is expected that this Thesis adds its contribute to the literature by proposing different scenarios of logistics networks, exemplified through different particular cases that will form the case study research method.

The research steps will proceed as follows:

1. Research step 1 – Scope definition and benchmarking: Collecting, organizing, selecting and analyzing qualitative and quantitative data with respect to worldwide suppliers of tertiary transport packaging products made from different sustainable materials, by comparing advantages and disadvantages of each one and while considering the creation of a new logistics network in which COMPANY A is the buying party, aiming to establish a new logistics network in Europe;

2. Research step 2 – Material-supplier selection: Since both qualitative analyzis and analyzis of quantitative data included many different variables and lead to inconclusive results, it should be used a suitable method for analyzing different criteria in the context of a decision-making situation. Considering the existing alternatives for this type of methods, the Multi-Criteria Decision Analyzis (MCDA) procedure is chosen and represents the method used for the material-supplier selection, the second step of the methodology. The swing weighting method will be used to proceed with a MCDA, based on a specific set of criteria, to determine the best material-supplier option considering the impact on sustainability and logistics performance of establishing a new logistics network in Europe of such product. Based on the final scores obtained, the highest score corresponding to the best material-supplier option will be selected to conduct a case study;

3. Research step 3 – Case study: Scenario-based analyzis: Considering the results obtained in the MCDA in research step 2, the existing logistics network of the chosen material-supplier option in its country of origin will be introduced. Moreover, the MCDA data for that material-supplier option is defined as the baseline scenario, considering the impact on sustainability and logistics performance of establishing a new logistics network in Europe of such product. Then, three scenarios of logistics networks will be created, assuming a neutral, an optimistic and a pessimistic logistics context from the perspective of COMPANY A as the buying party, aiming to establish a new logistics network in Europe. For the selected material-supplier option, the evaluation of the multiple scenarios of logistics networks is based on the set of criteria used in the MCDA, from which a set of KPIs will be defined in terms of economic, environmental and logistics impacts to present results and conclusions;

4. Research step 4 – Solutions proposal: Developing conclusions and proposing solutions and recommendations that can improve the performance of the selected logistics network, based on the results obtained from the scenario-based analyzis performed in research step 3.

1.5. Thesis Structure

This project is structured in the following manner, divided in 6 chapters:

Chapter 1: Introduction – Introduces the project by presenting its context and relevance. It also introduces the research problem and the objectives that the project aims to fulfill. The methodology to be developed is also resumed and the Thesis structure is outlined.

Chapter 2: Literature Review – Contains a review on the most important theoretical concepts that are relevant to be addressed for the development of this project. It is divided in three main sections: Circular Economy, Sustainability and Sustainable Packaging. These are then divided in sub-sections that detail important aspects.

Chapter 3: Methodology – Proposing, explaining and implementing a methodology that is expected to lead to the achievement of meaningful results for the development of the project. Includes in detail all of the research steps followed in the development of the project, which are structured and detailed in sub-steps.

Chapter 4: Results Analyzis – Analyzis of the results obtained after the implementation of the methodology, structured in accordance with the research steps and sub-steps.

Chapter 5: Conclusion – Identifying important conclusions based on the analyzis previously developed. Disclosing limitations of the study and suggesting guidelines for further investigation and development of the conducted study.

2. Literature Review

This chapter contains three main sections of an extensive review on the most meaningful concepts required for the development of the project and consists of a theoretical basis that is relevant for this research, in accordance with the proposed research question and to fulfil the objectives of the project.

In section 2.1., Linear Economy and Circular Economy concepts and definitions are discussed and presented as being opposite ideas. The Circular Economy is approached with more detail, including important contents such as its contribution for sustainable development, its recent adoption as an alternative to the Linear Economy and the major challenges that are associated to it. Afterwards, the main Circular Economy principles are identified.

In section 2.2., a sustainability explanation is presented. The concept of Closed-Loop Supply Chain is introduced, including the criteria to be defined, stakeholders involved, among other factors. Moreover, it contains some criteria on how to measure and evaluate sustainability within Supply Chain Management. Within this section, the concept of logistics network design is also introduced and analyzed.

To conclude, in section 2.3. the review shifts to packaging in a sustainability context and focuses on how sustainable packaging solutions are adopted and promoted and its relation to Supply Chain Management and logistics networks. On this matter, packaging decisions represent an important decision-making level during the process of designing a logistics network. This section also addresses the different packaging levels. Moreover, examples in the literature of packaging Closed-Loop Supply Chain networks are referenced.

The research conducted for this literature review was developed in accordance with the objectives proposed for the project. Therefore, the keywords "Linear Economy", "Circular Economy", "Sustainability", "Supply Chain Management", "Closed-Loop Supply Chain", "Logistics", "Logistics Network Design", "Packaging", "Transport Packaging" and "Tertiary Packaging" were used throughout the research process. The academic articles analyzed were retrieved from Scopus, Web of Science and Emerald Insight – Operations, Logistics & Quality databases.

2.1. Circular Economy

2.1.1. From Linear to Circular Economy

The Linear Economy (LE), commonly designed as the take-make-dispose model, is based on the constant use of large quantities of resources and energy, which are of easy access (Ellen MacArthur Foundation, 2013).

The LE is characterized for contributing to massive quantities of waste of both raw materials and finished products (Webster, 2016). It is a linear model of value creation that has been adopted by companies and consumers since the Industrial Revolution. In the LE, value creation begins with the extraction of raw materials and finishes with end-of-life disposal, expecting that customers use goods and discard them when they do not need them anymore, having to buy others and starting the cycle all over again (McKinsey & Company, 2016).

Accordingly, Korhonen, Honkasalo, and Seppälä (2018) also refer to the LE as a "linear throughput flow model", as well as the "traditional linear extract-produce-use-dump material and energy flow model of the modern economic system" (p. 37), in which materials have only one way, following one single flow.

Stahel (2016) compares the LE to a river, stating that it flows through various value-adding steps by transforming natural resources into raw materials and products to be sold. All the risks are transferred to the buyer at the moment of sale, including ownership and liability for the waste generated by the product. At this stage the buyer is already the product owner, who is free to decide on the type of end-of-life treatment to be applied to the product at the end of its cycle. Reuse, recycling but also dumping are among the alternatives, which is often common and contributes to the creation of waste and excessive resource usage, especially in saturated markets. Although being efficient at solving the problem of product scarcity, the LE encourages and allows companies to sell mass amounts of cheap goods, which contributes to excessively high levels of resource usage. Factors such as fashion, emotion and progress are the drivers of this take-make-dispose type of economy. On the other hand, the Circular Economy (CE) is compared to a lake, where the flow of goods and materials is circular, since these have to be reprocessed at their end-of-life to generate a closed-loop cycle. It creates jobs and saves energy, while reducing consumption of resources, as well as reducing waste.

According to de Koeijer et al. (2017), depreciation of raw materials and excess of waste is a direct consequence of the linear take-make-dispose systems. The fact that in these systems there is a common reliance on input raw materials, which then return to the original system on limited quantities after their end of life, contributes for these negative consequences.

The negative effects caused by the dominant development model of the LE are compromising the stability of the economies as well as the integrity of natural ecosystems which are crucial for humanity's survival (Ghisellini et al., 2016).

Despite the goal of achieving efficiency pursued by the LE, there is need for a systemic change of the entire operations. The fact that scarcity of resources and strict environmental standards are constantly increasing create the need for a shift in the economic mindset, especially at a time in which information technology is a key innovation resource and consumers are demonstrating a shift in their behavior patterns into more sustainable practices. The LE is not a sustainable solution in the long-term, since the finite stocks of the resources used make it inappropriate for the reality in which it functions. Although it has recently been embracing the goal of achieving efficiency, meaning, reducing resources and energy consumed per each unit of output produced, this will only delay an inevitable finite nature of the stocks that will negatively impact and compromise future generations (Ellen MacArthur Foundation, 2013).

Following this reasoning, Bonciu (2014) state that a planet with finite resources and limited absorption capacity regarding waste cannot aim at achieving sustainable economic growth by following a linear production model such as the LE.

In accordance with this perspective, there is a new business model, the CE, which is demonstrating capacity to contribute to a more sustainable development, as well as to a harmonious society (Ghisellini et al., 2016).

The Ellen MacArthur Foundation (2013) expects the transition to CE to be "as non-linear as its inner workings" (p. 78), with a relatively accelerated adoption. Among the factors contributing for that may be the quick growth of consumption patterns and the low extra costs for additional volumes once a circular solution is adopted.

Several authors highlight the importance of well-designed and effective indicators in the transition from the LE to the CE, which still faces some challenges to its development process (Elia et al., 2017).

Moreover, in recent literature sources the CE emerges as an alternative for the traditional LE, which is predominantly present within the current world (Farooque et al., 2019).

Although, the CE has faced some criticism, which involves the argument that it consists of a limited perspective of an economic model. One of those limitations is that it is often considered only as a method of achieving more proper waste management, which is likely to contribute to its failure. For this reason, the challenge consists of adopting a broader and highly comprehensive approach to the design of alternative solutions, that leads to the improvement of the entire economic and living model, when compared to the usual business economy and resource management. This way, material and energy recovery and regeneration that characterize the CE will form an integrated interaction among the process, the economy and the environment which will distinguish CE from any other approaches calling for green technologies and regenerative development (Ghisellini et al., 2016).

Moreover, CE's objective of eliminating the passive throwaway LE culture demands producers and consumers to turn into highly active intervenients in product recycling and reuse. The challenge here relies on the fact that recycling has its limits and it is unlikely that CE can keep up with the economic growth values that has recently been evidencing. On the other hand, recycling, reuse and recovery options may not fit within a certain context, while some types of technology-based end-of-life treatments can be more costly than the traditional technology methods used (Ghisellini et al., 2016).

Furthermore, Niero and Hauschild (2017) state that a major issue in assessing the effectiveness of CE strategies is to avoid optimizing one part of the value chain, like production, at the expense of other parts (e.g. end-of-life) or to end up favoring one category of stakeholders (e.g. consumers) at the expense of others (e.g. waste management operators and regulators). Another difficulty is to identify the positive aspects of circularity strategies, for example in terms of job creation, which is linked to the social sustainability.

Gupta et al. (2019) state that the transition into a CE needs to be performed with the aid of alterations within business operations, supply chains and logistics, as well as changing the nature of the product. The LE considers businesses as open loop systems, in which natural resources are sourced and used on a constant basis, regardless of its finite stock and high pollution and waste generation levels. On the other hand, the CE approaches businesses cycles as being closed-loop systems, which entail regenerative and restorative processes. The transition into the CE, a closed-loop business cycle, is deeply connected to the meaningful impact of the Reverse Logistics (RL) and Supply Chain Management (SCM). These areas make the difference in the transport of used products from customers to waste contractors and then to manufacturers all over again, in order to proceed with regeneration and restoring of products, eliminating waste.

Moreover, the CE is a recent economic perspective which needs further considerations regarding sustainability of supply chain operations, being that is relies on social, economic and environmental values (Genovese et al., 2017).

Korhonen, Honkasalo, and Seppälä (2018) highlight that "new business models including product design for multiple life cycles, leasing and renting the product while maintaining its ownership and reverse logistics in the supply chain have been proposed for CE" (p. 44).

For these reasons, CE appears as an appropriate method of trying to improve sustainability within products' life cycle, although it faces a considerable number of challenges. The closed-loop cycle is only complete when the recycled product becomes the raw material for that same product.

2.1.2. Circular Economy Definition and Principles

It can be stated that there is not a clear consensus between authors with respect to what should be a proper definition of the CE. One perspective argued that the concept has deep-rooted origins which were furtherly polished by different schools of thought and therefore cannot be associated to one single date or author (Ellen MacArthur Foundation, 2013). On the other hand, other authors previously tried to define it, one of them being Andersen (2007) who has provided evidence that CE is advantageous for both society and economy as a whole, meanwhile others back at the time stated that "there is no commonly accepted definition of CE so far" (Yuan et al., 2006, p. 5).

According to Ellen MacArthur Foundation (2013):

> A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models. (p. 7)

It is the most cited and famous definition of CE across academic papers.

According to the Ellen MacArthur Foundation (2013), the foundation of the CE concept is based on three principles:

- Design out waste and pollution;
- Keep products and materials in use;
- Regenerate natural systems.

Firstly, as its core objective, a CE aims to design out of waste. In a perfect circular system waste does not exist, since product design and optimization are performed in a way that products enter a continuous cycle of disassembly and reuse. This type of component and product cycles define the CE and set it apart from disposal practices. Even some recycling processes are not included within the CE parameters, namely those in which large amounts of energy as well as labor are unnecessarily lost or in which pollution is at a high level. Secondly, circularity strictly differentiates consumable from durable components of a product. The consumable components contained in a CE context are mostly made of biological ingredients or nutrients, which are non-toxic, may be beneficial and are expected to safely return to the biosphere, either in a direct way or in a flow of consecutive uses. On the other hand, durable components such as engines or computers are made of technical nutrients that cannot return to the biosphere, namely metals and most plastics. Therefore, these are designed for reuse right from the beginning. Finally, the energy required to fuel this continuous circular cycle should be renewable by nature, in order to decrease resource dependence, while increasing system resilience (Ellen MacArthur Foundation, 2013).

Desing et al. (2020) enhance that CE aims at closing the loops of materials, since it looks at end-of-life materials and products as resources, instead of waste. Therefore, it can be compared to an ecosystem, where the need for raw materials and disposal of waste is minimized. Moreover, the authors point that there is a major challenge for academics to overcome within the CE topic, since there is no agreement upon a definition nor its conceptual clarity. Kirchherr et al. (2017) had previously referred to this abundance of CE conceptualizations as a "circular economy babble" (p. 228). Blomsma and Brennan (2017) conceptualized CE as an "umbrella concept" (p. 604), which refers to a concept that usually has a predictable trajectory of development and arises when there is lack of guiding theories or development paradigm. Korhonen, Nuur, et al. (2018) argue that it has already become an essentially contested concept.

The CE can lead society to prosper, by achieving increased sustainability and well-being at low material, energy and environmental costs. It is also a possibility that these costs can be completely eliminated (Ghisellini et al., 2016).

According to the Ellen MacArthur Foundation (2015), the CE is fundamentally based on three principles, considered as measures for action to be taken concerning the development of this type of economy. These represent a highly detailed version of the 3 principles previously outlined by the Ellen MacArthur Foundation (2013) regarding the foundation of the CE concept, namely by demonstrating how to transform and apply the theoretical concepts into practical measures:

- *Principle 1: Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows.*

The first principle is based on the dematerialization process of utility, which is related to the balance of renewable resource flows. In order to fulfill resource gathering needs, a circular system will have to wisely select the necessary resources with the aid of processes and technologies that use renewable or better-performing resources, in cases where that is possible. This way, utility will be achieved through a virtual, dematerialized process (whenever it is optimal to do so). Moreover, the natural capital is enhanced by the CE because it encourages sustainable activities that create flows of nutrients within the system, such as creating conditions for the regeneration of soil, not compromising finite stocks.

- *Principle 2: Optimize resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles.*

In order to maintain technical components and materials in circulation within closed-loop material flows, techniques such as design for remanufacturing, refurbishing and recycling are a must follow. These circular systems methods extend products life and contribute for the optimization of maintenance and reuse, which maximizes utility and preserves energy spent during technical cycles. This process ends up contributing to development of the economy, using a circular approach.

Regarding the biological cycles, products are intentionally designed for consumption, achieving new resource economic value. Biological cycles create value by consecutively using products and materials for different applications, from which additional value is extracted. As for the biological nutrients, these re-enter the biosphere, turning into feedstock that can be used in a new cycle.

In both cases, the resource yields are optimized within a circular system that never compromises effectiveness.

- *Principle 3: Foster system effectiveness by revealing and designing out negative externalities.*

In the CE, negative externalities should be managed in order to reduce the damage potentially caused. These externalities include CO2 levels, traffic congestion time, non-cash health impacts of accidents, all types of pollution, release of toxic substances, climate change, among others. An example is that the circular model would benefit households by reducing the cost of time lost to congestion by 16% by 2030, and close to 60% by 2050 (Ellen MacArthur Foundation et al., 2015).

In addition, Cramer (2015) introduced different levels of circularity that can be distinguished according to the 9'Rs principle:

Refuse: Prevent the use of resources
Reduce: Decrease the use of resources
Re-use: Find new product use (second hand)
Repair: Maintain and repair
Refurbish: Improve product
Remanufacture: Create new product from second hand
Re-purpose: Re-use product for different purpose
Recycle: Re-use raw materials of product
Recover: Recover energy from waste

"*Refuse*" represents the highest level of circularity priority, while "*Recover*" represents the lowest.

On the other hand, Jawahir and Bradley (2016) state that throughout history CE has been based basically on the principles of 3Rs: *Reduce, Reuse* and *Recycle*.

Reduce: Deals with the first three stages of product lifecycle, namely the reduced use of resources in pre-manufacturing stages, reduced use of energy, materials and other resources and a reduced amount of emissions and waste throughout the use stage.

Reuse: Aiming at reducing the use of virgin materials during the manufacturing of new products, it is based on the reuse of a product consecutively after its first lifecycle, lasting for the next lifecycles.

Recycle: Converting materials that would be considered waste into new ones or into new products.

Nevertheless, the authors argue that 6R-based technological elements are essential for achieving economic growth, environmental protection and societal benefits. A 6R methodology provides a multiple product lifecycle, closed-loop system, which constitutes a basis for sustainable production. This system adds 3 new principles to the 3Rs and are also referred as “activities”: *Recover*, *Redesign* and *Remanufacture*.

Recover: At the end of the use stage, collecting products, disassembling sorting and cleaning for utilization in further lifecycles.

Redesign: Using materials and resources from previous lifecycles and previous generations of products to redesign next generation products, entering into a new lifecycle.

Remanufacture: Restoring used products to their original state through reprocessing methods or through reuse processes, without losing any functionality aspect.

According to Jawahir and Bradley (2016), this 6R-based closed-loop system is expected to “enable a near-perpetual material flow, while facilitating the optimal use of energy, raw materials and other resources, and will be expected to produce minimal waste and emissions at the end” (p. 105).

Later on, Ritzén and Sandström (2017) refer to a 4R-strategy, which includes *Repair*, *Reuse*, *Recycle* and also *Recondition*. In their perspective, the use of this strategy is required by CE to build on the principles of a spiral loop system, in which the intention is to maintain products in use and avoid disposal.

All in all, a CE is an industrial system whose principles are characterized for being restorative or regenerative by intention and design. Ghisellini et al. (2016) argue that sustainable development considers all of the economic, environmental, technological and social aspects in a balanced and simultaneous way. Therefore, a certain economy, sector or individual industrial process must achieve the interaction of all these factors in order to pursue a process of sustainable development. Following this reasoning, the CE is a positive contributor for the integration of all these aspects, due to the fact that its logic and principles rely on sustainability within the environmental, political, economic and business aspects. Moreover, it has the potential to understand as well as to implement radically new patterns that can contribute for the sustainable development of the society.

A CE contributes for the improvement of sustainability and ends up leading to improvements in both economic and environmental performance. Many negative environmental impacts, such as waste, energy consumption, transport processes and packaging can be avoided if companies establish closed-loop production systems (Winkler, 2011).

Being based on circular business models with the objective of reducing the need of using virgin raw materials, the CE is achieved by turning supply chains into closed-loops, therefore this is an important question to be reconsidered (Cramer, 2015).

2.2. Sustainability

2.2.1. Closed-Loop Supply Chain

In the perspective of logistics and supply chain within a CE, the CE principles reformulation can potentially be used in the supply chain, in order to achieve a more circular one, denominated by Closed-Loop Supply Chain (CLSC). The CLSC has two distinct flows. Firstly, the forward flows aiming to minimize services and cost, and on the other hand the reverse flows, related to the concept of RL, to recover the unwanted, broken or end-of-life products from customers to return to the manufacturers (Ripanti & Tjahjono, 2019).

Moreover, “closed-loop supply chains (CLSCs) focus on taking back products from customers and recovering added value by reusing the entire product, and/or some of its modules, components, and parts” (Guide Jr. & Van Wassenhove, 2009, p. 10). Based on this definition, Chen et al. (2017) moved on to the concept of CLSC management, which involves designing, controlling and operating a system to maximize value creation during the lifecycle of a product. This process is performed with dynamic recovery of the product’s value along time, assuming different types and volumes of value return.

Guide and Van Wassenhove (2009) argue that CLSC can be approached by focusing on the type of returns or on activities. Nevertheless, both views are linked because for each kind of product return there is a specific appropriate recovery activity. Therefore, product return-recovery pairs that add value are resumed in three types:

- Consumer returns – *Repair*;
- End-of-use returns – *Remanufacture;*
- End-of-life returns – *Recycle.*

The authors also point that CLSCs are characterized by an additional complexity to be designed, managed and controlled, which is due to a large number of actors acting in a decentralized system, in which there is not a single actor responsible of controlling the supply chain. The fact that reverse supply chains usually entail more independent players than forward supply chains makes its coordination more difficult.

Soleimani et al. (2017) also enhance that many stakeholders are involved within the context of a CLSC network design problem, in which suppliers, manufacturers, distribution centers, customers, central warehouses, return centers and recycling centers were considered. The objective was to maximize meeting customer demand and total profits, while minimizing lost working days due to occupational accidents.

Chen et al. (2017), still referring to CLSC management, add that:

> Operating procedures that entail adopting EOL recycling approaches provide a revolutionary method of supplying raw materials, reduce fabrication costs, and minimize resource consumption. In this scenario, forward and reverse logistics (FL/ RL) must be considered simultaneously when designing a complete supply chain network. (p. 111)

Amin et al. (2018) reflect on the same argument regarding CLSC. In their perspective, a CLSC network is formed by the combination of forward (traditional) logistics (FL) and RL. While FL aims at providing products for customers, RL has the ultimate goal of achieving economic and environmental value from returned products. CLSCs would, therefore, join these two goals together and share both ambitions. Taleizadeh et al. (2019) also state that a CLSC is a network that promotes integration of all the activities involved in both FL and RL, to avoid sub-optimality.

Chen et al. (2017) approached an integrated CLSC network in the form of a design problem. In this case, chain costs and environmental issues in the solar industry were considered from a sustainability perspective. The model included practical features such as flow conservation in each production/recycling unit of forward/reverse logistics (progressive flow or reverse flow, respectively) expansion of capacity, and recycled parts.

Mirzaee et al. (2018) highlight the first level of the closed-loop networks. At this level, suppliers highly influence the efficiency of the whole network, as approximately 70% of the product's cost is conditioned by the purchasing cost of raw materials from suppliers. According to Amin and Razmi (2009), selecting suppliers is a multi-criteria decision-making process that consists of both qualitative and quantitative factors.

Amin and Zhang (2012) point that supplier selection in CLSC networks has not been investigated as it occurred for open loop supply chains and that there are some important differences. Some criteria in CLSC has usually higher importance than it has for open-loop supply chains, namely product performance criteria and environmental criteria. Durability, strength and lightweight are important product performance criteria to be considered for CLSC, as products should have those characteristics in order to be reusable and recoverable, while the number of disposed products influences total cost. Concerning environmental criteria, some examples to be studied include recycling, clean technology, pollution reduction capacity and environmental costs. Moreover, Genovese et al. (2017) stated that environmental damages and costs can be reduced by selecting the best supplier, while leading to the circularity of used materials.

Furthermore, Govindan et al. (2020) enhance that "suppliers, as the first layer of the supply chain network, pose a great impact on environmental pollution" (p. 1). The authors aimed at integrating CE in supplier selection and supply chain network design, by focusing on minimization of the network costs and shortages. They developed mathematical models for circular supplier selection and order allocation, in the context of a multi-product Circular Closed-Loop Supply Chain (C-CLSC). The suppliers were evaluated following 3 criteria: Circularity, Quality and On-time Delivery.

CLSC reflects the adoption and implementation of CE into the SCM area, by complementing the traditional FL flows with RL processes in order to close the loop and restart the production cycle all over again. Consequently, it is likely that this supply chain model will contribute for an improvement in the performance of supply chains in terms of sustainability within its different spheres.

2.2.2. Sustainable Supply Chain

The World Commission on Environment and Development (WCED, 1987) defined the concept of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (p. 41). It is referred as being a process of change, that contains aspects such as resources exploitation, investments direction, technological development orientation and institutional change, which are in harmony to ensure current and future potential to meet human needs and wishes.

Glover et al. (2014) point out that "sustainability is a concept that is vague, ambiguous, pluralistic, contested, and grounded in different value systems" (p.103). The authors refer to sustainable development as an important agenda in the modern business world.

Furthermore, in 2015, all of the United Nations Member States adopted a plan in order to build a better world for people and for the planet, to be achieved by 2030. It was named "The 2030 Agenda for Sustainable Development" and contains at its core the 17 Sustainable Development Goals (SDGs). These represent an urgent call for action by all developed and developing countries for people, planet and prosperity in areas of critical importance that include key aspects such as sustainable consumption and production in order to sustainably manage the planet's resources, ensuring prosperity and peace and implementing the agenda through a revitalized Global Partnership for Sustainable Development (United Nations, n.d.).

The scarcity of natural resources, in addition to an increasing social responsibility movement observed within companies has caused firms and researchers to focus on sustainable approaches. One of the consequences of this focus is the Sustainable Supply Chain Management concept (SSCM) (Yousefi et al., 2016).

There is a deep ambiguity embedded in the sustainability concept of supply chains. This is among other factors, due to the fact that professionals struggle to clearly design sustainable supply chain processes and networks (Eskandarpour et al., 2015).

Although many concepts of sustainability can be found in the literature, the triple bottom line approach is a commonly highlighted concept, according to which sustainability revolves around 3 main dimensions – environmental, economic and social – where a minimum performance is to be achieved (Elkington, 2002).

Seuring and Müller (2008) define SSCM as:

> The management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements. In sustainable supply chains, environmental and social criteria need to be fulfilled by the members to remain within the supply chain, while it is expected that competitiveness would be maintained through meeting customer needs and related economic criteria. (p. 1700)

Each one of these 3 dimensions can be analyzed assuming different perspectives and measured according to different indicators.

Within SCM, the economic criteria are being complemented by the social and environmental criteria due to some pressures (Yousefi et al., 2016). Focal companies - those commanding the supply chain, establishing the direct link between customers and suppliers and designing the product or service - are forced by stakeholders to consider the environmental and social issues embedded in their supply chain. Furthermore, problems such as poor working conditions and local environment contaminations occurring in major apparel distributors were among the triggers contributing for an increasing interest in green SSCM, in which environmental and social issues are gaining importance besides the economic ones (Seuring & Müller, 2008).

Bai and Sarkis (2010) argue that economic criteria to be considered in SCM evaluation include price, quality, flexibility and supplier reputation.

Following this reasoning, according to Haddach et al. (2017) the major objective of SCM was to minimize costs, provide a good service level and perform an appropriate allocation of activities to production, distribution and transport stakeholders in order to increase the competitiveness of the industry. On the other hand, the integration of societal and environmental impacts is an objective that currently must be achieved by supply chains in order to increase their performance. Moreover, "supply chains must develop methods and approaches to consider and measure their impacts on economic, environmental and social levels and analyze interactions between these impacts" (p.401).

In accordance with this perspective, Kahi et al. (2017) state that currently, sustainability factors play a critical role in long-term achievement of SCM, which complicates the purchasing process with social and environmental pressures.

When addressing how to evaluate sustainability of SCM, Kahi et al. (2017) mention the perspective that:

> Decision-makers encounter some discretionary/free and even contradictory criteria while evaluating sustainability of SCM. Dual-role links, inputs, desirable and undesirable outputs are some of the main criteria. In an accurate appraisal of supply chain, interactions among suppliers should be taken into consideration. To evaluate sustainability of SCM, dealing with multiple criteria has been one of the significant concerns in preceding models (Yousefi et al., 2016). (p. 1867)

Recently, Narimissa et al. (2020) present the foundations of a proposed framework for the evaluation of SSCM performance. It consists of four layers, namely Dimensions, Aspects, Indicators and Measures and three dimensions, which are the Economic, Environmental and Social. Such framework was built upon the work developed by Disano (2007), Searcy et al. (2009), Zhang (2011), Ahi and Searcy (2015), Huang (2017), among others. These studies are more relevant than others for the basis of the framework because they analyzed the Dimensions, Aspects and Indicators layers considering all of the three Economic, Environmental and Social perspectives for each layer.

This study, conducted to an oil company in Iran, concluded that the following aspects would be relevant to measure sustainability:

Economic: Reliability; Responsibility; Flexibility; Cost; Quality; Return goods; Information; Supplier evaluation; Customer satisfactions.

Environmental: Green SCM; RL and recycle; Environmental management; Environmental hazards and pollution control.

Social: Immune system and occupational health; Staff training; Improve the working environmental; Supplier evaluation on social aspect; Employment; Non-discrimination and respect for justice; Customer satisfaction on social aspect.

It is stated that it is important to understand the most important economic, environmental, and social dimensions, in order to determine the proper sustainability indicators to be used in the assessment of supply chain sustainability.

Considering sustainable supply chains complexity, it is recommended that decision makers examine the different aspects of sustainability and their impact on different supply chain segments, rather than deciding in a particular area, because the consequences of decision making in one area will certainly affect other areas. This has led to a growing interest in the area of SSCM, which focuses on the CE to incorporate its principles into SCM, building reverse supply chains that boost sustainability.

Concerning CLSCs, the whole supply chain from suppliers to recyclers is under consideration (Govindan et al., 2015). This requires a complete design and configuration of the supply chain network, in order to create the most efficient network possible, meeting customer’s demand, ensuring the lowest possible cost and more importantly ensuring that sustainability and CE procedures are being implemented, while a closed-loop is actually being created. It leads to the concept of supply chain and logistics network design.

2.2.3. Logistics Network Design

In the current competitive business context, companies must perform actions to improve their processes in terms of their efficiency and sustainability, especially in what concerns the logistics area (García-Arca et al., 2014).

Simchi et al. (2000) argue that the commonly used term of supply chain can be denominated as logistics network, when it is intended to describe and analyze physical distribution issues. The logistics network is composed by suppliers, warehouses, distribution centers, retail outlets, raw materials, work-in-progress inventory and finished products that flow between the facilities. Network configuration can involve aspects concerning plant, warehouse and retailer location and an important issue is how the facilities and materials relate to each other, representing a physical form of structure.

Meepetchdee and Shah (2007) argue that the design and implementation of the logistical network is a strategic decision whose impact will last for many years, during which the business environment may suffer alterations. Strategic logistical network design is considered to be one of the core areas of supply chain design. This is a process used by supply chain managers to achieve the optimal number, location and size of warehouses and/or plants, to identify optimal sourcing strategies and to determine the best distribution channels, meaning, which warehouses should be positioned to serve which customers. Usually, the main objective is to minimize total costs, including sourcing, production, transportation, warehousing and inventory, through the identification of the optimal trade-offs between the number of facilities and service levels. The design of a logistics network is usually based on the use of aggregated data and long-term forecasts, being a process that takes a few years to be completed. In accordance, Pishvaee et al. (2010) add that any intended change to be performed in a logistics network design is not viable to be concluded within a short run timeframe, since this concerns expensive and time-consuming processes (e.g. opening and closing a certain facility).

Moreover, strategic decisions such as designing a logistics network will condition tactical and operational decisions. Therefore, the logistics network configuration is a process that will influence and constrain future decisions to be made at both tactical and operational levels (Pishvaee et al., 2010).

Logistic network design plays an important strategic role in efficient and effective SCM. It commonly involves multiple although conflicting goals, such as cost/profit, resource balance, customer responsiveness, quality, among others (Ramezani et al., 2013).

Organizations have been pushed by consumers and by the government to redesign their logistics networks, so that they turn into more environmentally friendly ones, while remaining cost efficient. This reveals a development in the main objective of logistics network design from cost minimization only, to cost and environmental impact minimization (Frota Neto et al., 2008).

In accordance, Bing et al. (2014) postulate that environmental concerns are an aspect which is gaining increasing importance in the logistics network design process.

The majority of the literature in logistics network design focuses on FL network design. There are also some authors that studied RL network design and in recent years a few papers have worked with integrated logistics network design (Pishvaee et al., 2010).

RL networks design is concerned with the number of collection centers, recovery centers and disposal centers needed in a network of this type, as well as with their locations and capacities. The product flows amongst these facilities is also a matter of concern (Ferri et al., 2015).

Paydar and Olfati (2018) realized that factors such as the lack of valuable resources, economic importance, environmental issues and increased customers' awareness influenced researchers to consider and focus on the design of a RL network.

Van Engeland et al. (2020) also approached network design in the context of waste management and RL. It is argued that in case the market for recovered products differs from the initial end consumer, the network is denominated as open loop. On the other hand, if the product flow returns to the same market after the recovery process, the network is said to be a closed-loop one.

Logistics network design is among the most important strategic decisions within the context of SCM, due to its impact on the efficiency and responsiveness of the supply chain. Decisions on the number of facilities, their locations and capacities, as well as the quantity of flow between them are common examples of the design of a logistics network and will not only influence costs, but also customer service levels. For this reason, companies with an effective and efficient supply chain design are more likely to achieve a sustainable competitive advantage.

Simchi et al. (2000) state that an example of a complete analyzis of SCM is the process of developing sustainable transport packaging solutions, as it concerns physical distribution issues, which leads to the concept of logistics network and reflects the need for the design of such a system. In order to develop sustainable transport packaging solutions, within the scope of the CE, there is the need to involve raw material suppliers and packaging manufacturers, transport companies, product growers or manufacturers, wholesalers, distributors, waste contractors and recyclers to proceed with the end-of-life treatment.

2.3. Sustainable Packaging

Not so many years ago, Gutta et al. (2013) stated that a trend had emerged in the industry, that promoted the use of environmentally friendly materials for packaging.

Previously, the SPC (2011) had defined sustainable packaging according to the following criteria:

A. Is beneficial, safe & healthy for individuals and communities throughout its life cycle;
B. Meets market criteria for performance and cost;
C. Is sourced, manufactured, transported, and recycled using renewable energy;
D. Optimizes the use of renewable or recycled source materials;
E. Is manufactured using clean production technologies and best practices;
F. Is made from materials healthy throughout the life cycle;
G. Is physically designed to optimize materials and energy;
H. Is effectively recovered and utilized in biological and/or industrial closed-loop cycles.

According to Singhry (2015), packaging must be effective, efficient, cyclical and safe so that it can be considered to be sustainable. In order to be effective, packaging must have economic, environmental, and social benefits. To achieve efficiency, the cost of materials and energy must be resourceful. To be cyclical, the materials must be recycled after their initial life cycle and to ensure safety, packaging components must be non-toxic and non-polluting.

Product packaging is built in order to provide safe delivery, better brand perception and usually should highlight the sense of newness on the costumer. At the same time, the product packages are also meaningless to the user and are quickly discarded as waste, which creates high levels of waste for the environment. These may be solid wastes in landfill or dumping's in water and thus creates an impact on the environment. The production of this packaging products also contributes for the increase of the amount of pollutants in the environment (Singh et al., 2018).

In accordance with this perspective, Meherishi et al. (2019) argue that "unsustainable packaging and subsequent consumption practices have emerged as a threat to sustainable development and ultimately to the development of a circular economy" (p. 1).

When one thinks of packaging, most of the times it is the consumer-facing packaging that comes to mind at first place. Nevertheless, the packaging faces a high usage throughout the supply chain before reaching a final consumer. This is named as transport packaging, mostly used in industrial business contexts within the supply chains (SPC, 2018).

Packaging is divided in three levels, namely primary, secondary and tertiary. Primary packaging is the one that contains the product, providing protection and containment. Although, it is not necessarily suitable for transport. Secondary packaging contains one or more primary packages for use during transport, common examples include bags and boxes. Finally, tertiary packaging contains secondary packages and common types include pallets, skids, roll containers, trays, among others (Chung et al., 2018).

Meherishi et al. (2019) introduce a review on the concept of Sustainable Packaging in Supply Chain Management (SPSCM), affirming that a comprehension of the life cycles of the different tiers of packaging (primary, secondary, tertiary), meaning the different levels of packaging products along the supply chain provides contribute of greater value to SPSCM in practice and enable CE for packaging.

Moreover, a distinction is made between packaging used in the consumer supply chain (for individual consumers or households) and packaging that fits in an industrial supply chain, named as industrial packaging. When selecting an industrial packaging system, the aim should be to ensure the efficient use of materials with the lowest environmental impact, meanwhile providing minimum protection to the products inside.

Organizations involved in industrial packaging supply chains include packaging raw material suppliers, packaging manufacturers, transport companies, product growers or manufacturers, wholesalers, distributors, waste contractors and recyclers (Verghese & Lewis, 2007).

The integrated concept of SPSCM already poses a broad scope of analyzis, that includes the main keywords of sustainability, packaging, SCM and the associated logistics, while being deeply related to the adoption of CE practices. Nevertheless, there is still the need to assess the existing sustainability evaluation practices within the literature in order to choose the right methodology tools, to come up with the proper logistics networks for the packaging products.

There are many cases of design of RL networks involving packaging solutions. Moore (2005) states that packaging reuse is among the several benefits that can be achieved from an effective RL program. As an example, returnable packaging products to be recycled or reused can generate customer satisfaction, as they do not generate waste at the final customer.

Silva et al. (2013) highlight that environmental issues are one of the main reasons for the promotion of RL within companies, especially for the industrial packaging business. Industrial packaging is likely to develop technical, environmental and economic benefits for companies that have managed to adopt an adequate RL system for packaging.

According to Sarkar et al. (2019), "recent advances in the product packaging materials have enabled the supply chain management systems to adopt returnable transport packaging policies to achieve economic and environmental sustainability" (p. 987).

On the other hand, Leite (2009) points that returnable packaging has also disadvantages likewise disposable packaging, naming capital invested, direct and reverse transportation costs, flow management, reception, cleaning, repair and storage, nevertheless the benefits can outweigh the costs. Higher product protection, environmental benefits, higher flexibility for the costumer in case of legal requirement changes and returnable packaging as a secondary material for the manufacturer to produce new types of packaging are among the advantages of returnable packaging.

Baruffaldi et al. (2019), however, reminded the perspective in which "the reverse flows of packaging from consumers to suppliers increase the complexity of the logistics network when compared to the traditional one-way system (Wu and Dunn, 1995)" (p. 293).

Nevertheless, the implementation of a reusable packaging system is dependent on the creation of a closed-loop network, that is able to manage the packaging product along its entire life cycle (Guide Jr. & Van Wassenhove, 2009).

Following this reasoning, Accorsi et al. (2014) add that the package has to travel along a wider network, which contributes for higher transportation costs and greater environmental impacts.

Baruffaldi et al. (2019) present a methodology and a decision-support tool to quantify the logistic and environmental impacts associated with packaging distribution in the closed-loop network between growers, retailers, and the pooler. It quantifies costs and benefits resulting from different logistics scenarios created for reusable packaging networks for food products.

Meherishi et al. (2019) argue that:

> With growing popularity of concepts such as circular economy and sustainability, packaging and its relationship with sustainability and supply chain management in a circular economy needs to be studied. With increasing pressure for supply chains to be sustainable in all aspects, it is the need of the hour to understand the role of packaging as a sustainable practice to develop a circular economy. (pp. 1–2)

Within SCM, packaging plays an important role to prevent the product from suffering damages during transit along its journey across every stakeholder involved in the supply chain network. In a CLSC, it has even higher importance, as it is integrated in a network that represents an integrated coordination of forward and reverse SCM systems. As a result, it should be properly managed, especially concerning the choice of returnable transport packaging solutions, that play a meaningful role for the development of RL and ultimately of CLSCs. The type of end-of-life treatment applied to the packaging products is deeply related to the RL created by a CLSC and can be achieve exactly through CE practices.

Packaging design is an important step within packaging supply chain, where manufacturers and consumer-packaged goods companies are constantly considering new materials and formats. As a result, they could collaborate with waste-collection and recycling companies to choose recycling-friendly options, enhancing sustainability and contributing for the shift into a CE (McKinsey & Company, 2016).

2.4. Literature Review Summary

The take-make-dispose linear system based on the LE is clearly not a sustainable economic model. It is reflecting an excessive use of resources and energy, which cannot achieve sustainable economic growth in the context of the Earth’s resource availability. Ultimately, it will end up compromising the economic and environmental stability that is needed to extend the current standards of living to future generations. Therefore, this unsustainable model of resource utilization must be adapted into a circular one.

Accordingly, the CE is the economic model that demonstrates the greatest capacity to change the paradigm by making use of technical and biological cycles, in the context of an economy that is restorative or regenerative by intention and design. It is based on three main principles, that includes designing out of waste and pollution, keeping products and materials in constant use and regenerating natural systems to the maximum possible extent. Despite the existence of some criticism, a CE contributes for the improvement of sustainability, transforming supply chains into closed-loop production systems.

In the scope of logistics and SCM, CLSC reflects the adoption and implementation of the circular economic model, as it complements forward flows with reverse flows by introducing RL into the whole process. This type of supply chain model is highly likely to contribute for an improvement in the sustainability performance in the context of SCM. Following this reasoning, the SDGs targets must be a reference in terms of how sustainability can and should be achieved, representing a critical call for action that must be implemented into production systems and considered as guidelines to follow in order to ensure sustainable resource management practices. A meaningful example of the incorporation of sustainability and the SDGs targets into SCM is the concept of SSCM.

SSCM and concretely CLSC, due to its complexity, require a complete design of the whole supply chain network, from suppliers to recyclers, which is achieved through logistics network design. This process is among the most important SCM strategic decisions and reflect a complete analyzis that is likely to achieve sustainable competitive advantage.

The process of developing sustainable transport packaging solutions is an example of a complete and exhaust SCM design. The development of sustainable packaging solutions requires the involvement of several stakeholders, considering that a CE model should be achieved through the inclusion of stakeholders such as recyclers and waste contractors into the process.

The project to be developed in this Thesis proposes to fill a gap in the literature, emerged by a company's challenge of providing more sustainable tertiary transport packaging products. This will be performed by integrating all of the above-mentioned concepts and designing logistics networks that consider the CE model, while maximizing the Sustainability of a logistics network. The scenario creation step plays a major role in the fulfillment of the gap in the literature, as it considers different possibilities that can occur in the context of such a circular model and that will reflect different levels of sustainability, an aspect that is not addressed by authors in the studies developed.

3. Methodology

Defining and creating different possibilities of logistics networks that reflect the entire supply chain system will provide results regarding the tertiary transport packaging product's economic, environmental and logistics impacts. This will depend on a meaningful set of criteria for the characterization of the logistics networks. In essence, the worldwide market of suppliers of tertiary transport packaging products, the logistics, transportation and packaging sectors and the potential clients for sustainable packaging solutions form the context basis of this research.

The methodology is focused on an analyzis of a selected sample of companies, suppliers of tertiary transport packaging products, which have potential to integrate a new logistics network in which COMPANY A is the buying party, aiming to design and establish a new logistics network in Europe. Firstly, a qualitative analyzis is performed, considering economic, environmental and social impacts of sustainability and the logistics performance of such logistics network design. Although, there is evidence that there is a low and meaningless impact of the suppliers' business on the social pillar of sustainability. Therefore, it will be disregarded in the analyzis of quantitative data, as well as 2 companies from the original sample, since it was not possible to conduct an interview. Despite important commonalities verified, both analyzes are inconclusive regarding the selection of the best material-supplier option since the companies share an equilibrium in this evaluation. For this reason, a MCDA is performed, using data collected from the two previous analyzes.

It is performed a choice of the best material-supplier option among the sample, considering logistics, economic and environmental performance of the establishment of such logistics network. Finally, a case-study is built in which new logistics networks are designed for the best material-supplier option assuming neutral, optimistic and pessimistic logistics scenarios from the perspective of COMPANY A, considering economic and environmental viability of establishing a new logistics network in Europe. Last but not least, the scenarios are submitted to an evaluation performed according to KPIs defined based on the set of criteria used in the MCDA.

The methodology comprises 4 steps, which are briefly described below:

1. Research step 1 – Scope definition and benchmarking: Collecting, organizing, selecting and analyzing qualitative and quantitative data with respect to worldwide suppliers of tertiary transport packaging products made from different sustainable materials, by

comparing advantages and disadvantages of each one and while considering the creation of a new logistics network in which COMPANY A is the buying party, aiming to establish a new logistics network in Europe;

2. Research step 2 – Material-supplier selection: Since both qualitative analyzis and analyzis of quantitative data included many different variables and lead to inconclusive results, it should be used a suitable method for analyzing different criteria in the context of a decision-making situation. Considering the existing alternatives for this type of methods, the MCDA procedure is chosen and represents the method used for the material-supplier selection, the second step of the methodology. The swing weighting method will be used to proceed with a MCDA, based on a specific set of criteria, to determine the best material-supplier option considering the impact on sustainability and logistics performance of establishing a new logistics network in Europe of such product. Based on the final scores obtained, the highest score corresponding to the best material-supplier option will be selected to conduct a case study;

3. Research step 3 – Case study: Scenario-based analyzis: Considering the results obtained in the MCDA in research step 2, the existing logistics network of the chosen material-supplier option in its country of origin will be introduced. Moreover, the MCDA data for that material-supplier option is defined as the baseline scenario, considering the impact on sustainability and logistics performance of establishing a new logistics network in Europe of such product. Then, three scenarios of logistics networks will be created, assuming a neutral, an optimistic and a pessimistic logistics context from the perspective of COMPANY A as the buying party, aiming to establish a new logistics network in Europe. For the selected material-supplier option, the evaluation of the multiple scenarios of logistics networks is based on the set of criteria used in the MCDA, from which a set of KPIs will be defined in terms of economic, environmental and logistics impacts to present results and conclusions;

4. Research step 4 – Solutions proposal: Developing conclusions and proposing solutions and recommendations that can improve the performance of the selected logistics network, based on the results obtained from the scenario-based analyzis performed in research step 3.

In the following section, each step of the methodology will be described in detail. Each research step will include sub-steps, schematized in Figures 3.1, 3.2, 3.3 and 3.4 that detail in a structured way the methodology applied.

3.1. Research step 1 – Scope definition and benchmarking

Firstly, the implementation of the methodology starts with the scope definition sub-step, as schematized in Figure 3.1. It then proceeds with the benchmarking process, which will allow to explain in detail meaningful aspects for the development of the project. Moreover, the methods used to gather information are described and afterwards the qualitative analyzis and analyzis of quantitative data are performed, following this order. Finally, conclusions are presented based on a comparative evaluation of all the material-supplier options included in both analyzes.

Figure 3.1 – Sub-steps of research step 1

Scope definition

The first step of the methodology will introduce the scope of the project, which concerns all the aspects relevant to be previously defined so that alternative logistics networks that might lead to more sustainable packaging solutions can be identified. These aspects are basically data that should be identified based on benchmarking of what already exists within sustainable tertiary packaging solutions for transportation, using CE approaches. The benchmarking is performed to provide an explanation of the details of the project: type of packaging products, type of materials used, existing worldwide suppliers and circular systems already used by companies, as well as types of end-of-life treatment given to products.

Benchmarking and details explanation

As previously stated in Chapters 1 and 2, packaging is divided in three levels, namely primary, secondary and tertiary. The tertiary/industrial packaging is the type of transport packaging to be analyzed and it has a considerable impact in the increase of logistics efficiency. The challenge created by the fact that transport packaging currently produces a lot of packaging waste on a daily basis is a trigger to design logistics supplying methods that aim to eliminate an excessive waste, for which consumers are increasingly aware. A meaningful type of tertiary transport packaging product to analyze are pallets. This will be the product analyzed because pallets are the most widespread packaging type used for material handling and transportation, therefore representing a critical asset in logistics systems. Despite that different materials can be used for the production of pallets, wood is the most commonly used material worldwide (Buehlmann et al., 2009) and particularly in the US and in Europe (Tornese et al., 2019).

Different suppliers of pallet products made from different materials (not necessarily wood) are approached in the methodology of this project. The selected suppliers are chosen because they provide sustainable solutions, with potential to integrate a CLSC. The criteria used to select the sample of companies are:

1. Producing and supplying tertiary transport packaging solutions – Pallets;
2. Using sustainable natural and/or recyclable materials to manufacture their products;
3. Products that are feasible to be included in a CLSC logistics network (End-of-Life options that fit in a CE context must be available);
4. Considering the creation of a new logistics network in which COMPANY A is the buying party, aiming to establish a new logistics network in Europe.

The final sample of companies built according to the criteria previously described forms a set of logistics networks that can supply COMPANY A. These logistics networks start at each company's production facility, their route is set to Portugal (COMPANY A's facilities) and are analyzed assuming their economic, environmental and logistics potential to move and establish such network in Europe. Furthermore, in Chapter 4, the suppliers are introduced and information about each one is presented in detail.

Methods

The benchmarking and the qualitative analyzis will be performed by online research and the keywords used are "Circular Economy", "Sustainable Supply Chain Management", "Closed-Loop Supply Chain", "Sustainable Logistics Network", "Tertiary Transport Packaging Suppliers", "Sustainable Pallet Suppliers" and "Natural/Recyclable/Alternative Pallet Materials". Moreover, interviews will be conducted to previously selected companies, to gather important quantitative information for the analyzis of quantitative data. These will be conducted to the companies' Chief Executive Officers (CEOs) or to other top management positions when the CEO is not available.

Qualitative analyzis

The logistics networks of the selected sample of companies will firstly be analyzed from the point of view of their economic, environmental and social impact on sustainability, always considering their logistics performance. The data, collected from online research, is then structured and split into advantages and disadvantages for each material-supplier option. Finally, a comparative analyzis is performed at the end, to decide on which companies to focus on.

Analyzis of quantitative data

Such as for the qualitative analyzis, the analyzis of quantitative data will focus on meaningful criteria that can evaluate the same material-supplier options from the perspective of their logistics performance and impact on economic and environmental sustainability. Interviews will be conducted to the companies' Chief Executive Officers or to other top management positions when the CEO is not available. In these interviews, interviewees will be asked about quantitative values for each criterion defined. Although, it was not possible to conduct interviews to 2 companies, therefore they will be disregarded in this analyzis. The social pillar is also disregarded in this analyzis, since the qualitative analyzis demonstrated a low and not so meaningful impact on this subject. Moreover, the environmental pillar of sustainability is difficult to quantify, so it is implicit in some of the economic and logistics criteria used. The set of criteria is defined according to the following:

- The perspectives of stakeholders involved in the tertiary transport packaging sector;
- Contains important quantitative information to be described regarding pallets specifications;
- Considers the economic, environmental and logistics impact, in quantitative terms, of the creation of a new logistics network in which COMPANY A is the buying party, aiming to establish a new logistics network in Europe.

Moreover, the data collected from the interviews is attached to each criterion and a comparison of all the material-supplier options is performed at the end, in addition to the qualitative analyzis, to decide on which companies to focus on. The monetary data is disclosed in US dollars, as most of the companies in the sample use this currency and provide the data in that way.

Comparative evaluation and conclusions

At the end of this research step, both comparative qualitative analyzis and analyzis of quantitative data will be performed by comparing advantages and disadvantages of each set of material and its supplier (material-supplier option) to evaluate the best option among different choices. Moreover, conclusions will be presented and then the methodology will proceed accordingly.

It is expected that both analyzes lead to conclusions regarding which material-supplier option is the most appropriate to focus on to design a new logistics network in which COMPANY A is the buying party, aiming to establish a new logistics network in Europe and then proceed with a case study of its logistics network.

3.2. Research step 2 – Material-supplier selection

In order to proceed with a deep evaluation of the material-supplier options, several variables must be considered. For this reason and since both qualitative analyzis and analyzis of quantitative data included many different variables and lead to inconclusive results, it should be used a method that is suitable for analyzing different criteria in the context of a decision-making situation. Considering the existing alternatives of this type of methods, the MCDA procedure was chosen and represents the method used for the material-supplier selection, the second step of the methodology.

Figure 3.2 schematizes the sub-steps included in this second research step, those that are needed to perform a MCDA. Firstly, a set of criteria will be selected and each criterion will be assigned with a definition. Then, a relative weight is assigned to each criterion, using the swing weighting method. The (UK) Department of Communities and Local Government (2009) resumes the process as:

> The method of eliciting relative weights on different criteria. Swing weighting requires judgements of the swing in preference from 0 to 100 on one preference scale as

> compared to the 0-to-100 swing on another preference scale. The judgements are made by considering the difference between the 0 and 100 positions, and how much that difference matters. Those two considerations take account of the range of real-world difference in the options on the criteria, and the importance of that difference to achieving the overall objective. Swing weighting results in ratio-scale numbers that reflect the relative importance of the criteria. (p. 153)

Finally, in the last sub-step, each material-supplier option is evaluated and the best one is chosen.

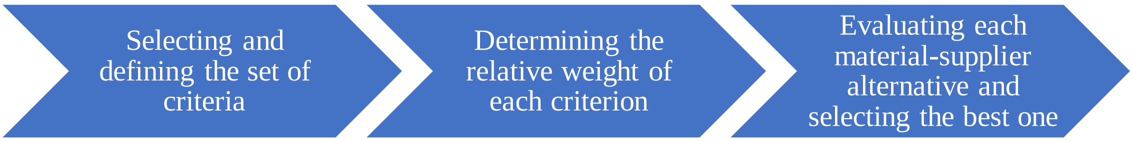

Figure 3.2 – Sub-steps of research step 2

Selecting and defining the set of criteria

In accordance with the information gathered in the analyzis in research step 1, the perspectives of stakeholders involved in the tertiary transport packaging sector, the literature review and the criteria previously defined for the analyzis of quantitative data, an appropriate set of criteria was developed, able to evaluate and rank the selected supplier's logistics networks in economic, logistics and environmental terms. It consists of a set of criteria that can evaluate a logistics network along its entire process and not only in quantitative terms, but also using qualitative criteria, therefore it is more complete than the previous one. It also considers the design of a new logistics network in which COMPANY A is the buying party, aiming to establish a new logistics network in Europe of the chosen material-supplier option. This set of criteria is presented in Chapter 4, along with its definitions.

Determining the relative weight of each criterion

In order to proceed with the MCDA, the relative weight of each criterion has to be determined. The swing weighting method is the chosen procedure to assign each criterion with a relative importance. The swing weighting procedure is a simple, easy-to-use weighting method based on ratio estimation. It is considered a method of MCDA, as it evaluates a set of options using several criteria (Mustajoki et al., 2005). The swing weighting method is inserted within a common basis of many MCDA studies that were performed and its usefulness relies on procedural issues (Belton & Stewart, 2002). This method not only does capture intrinsic, but also the relative importance of the decision-making criteria to be assessed.

In this method, the “swing” refers to a change from the worst to the best value on each criterion (Belton & Stewart, 2002). It is a trade-off weighting method, in which the relative importance of the criteria is calculated on the basis of moving from the worst to the best score on a scale (Leijten et al., 2017).

Bana e Costa et al. (2009) point that swing weighting is structured in 3 steps:

1) Ranking the criteria in terms of importance;
2) Quantifying the criteria;
3) Normalizing the values into weights

In step 1, the worst possible scenario whereby just one criterion can be changed to the best is proposed to a decision maker, that has to choose it right away. The process is consecutively repeated until there are no criteria left. In this method, the most important criterion that is firstly changed from worst to best is worth 100 points (Leijten et al., 2017). This criterion becomes the standard to which all other criteria are compared (Bana e Costa et al., 2009). Afterwards, in step 2, the respondent (decision-maker) is asked on a scale from 0 to 100, what the weight of a full swing on the second most important criterion would be, meaning, what would be its relative importance in comparison to the standard criterion. If this would be given a score of 50, this would mean that it is half as important as the first criterion. This is performed for all criteria, and then step 3 enters the picture, in which all of the 0-100 scores are normalized into weights, so that its sum equals to 1 (Edwards & Barron, 1994).

At this point, the swing weighting method will now allow to attach a weight to each criterion, based on its importance and perform the MCDA.

Regarding the decision-making process for the creation of the weights, two individuals were involved in it, namely an expert in CE and an expert in Management. The process was developed with the aid of online available information of the suppliers and structured interviews conducted between the decision-makers. It included a guideline with the following questions, represented in Table 3.1.

Table 3.1 – Swing weighting method: Interview guideline

Swing weighting step	Question
Introduction	"Please consider the objective of creating a logistics network of sustainable tertiary transport packaging products (pallets). The following set of criteria contains critical aspects of the logistics network, which are all at their worst performance levels."
1) Ranking the criteria in terms of importance	1: "If you could increase the performance of this logistics network by targeting only one criterion, increasing its performance from worst to an optimal level, which one would you change?"
	2: "Excluding the previous criterion, which one would you choose to increase from its worst to optimal level? Repeat the process until every criterion is ranked."
2) Quantifying the criteria	3: "Considering that the increase (swing) from worst to optimal level of performance in the criterion chosen in question 1 weights 100 points, how much would you score a swing from worst to optimal level in the criterion chosen in question 2? Repeat the process until every criterion is scored."

Afterwards, the values are normalized into weights (step 3 of swing weighting) and each criterion will contain a weight attached to it. The normalization is developed in accordance with the following equation:

$$k_j = \frac{k'_j}{\sum_{j=1}^{n} k'_j} , \forall\, j \in J \qquad (3.1)$$

In which:

J: Set that includes the whole set of criteria

n: Total number of criteria included in the set of criteria

k'_j : Score of criterion j in the non-normalized scale (obtained following the protocol described in Table 3.1)

k_j : Weight of criterion j in the normalized scale

Evaluating each material-supplier alternative and selecting the best one

Last but not least, a MCDA will be performed to decide on the best material-supplier option to focus on. Chapter 4 contains in detail the results of the decision-making procedure of the swing weighting method and of the MCDA, as well as its explanation.

Concerning the MCDA, the data gathered in the previous qualitative analyzis and analyzis of quantitative data is used and attached to each criterion. Some values were assumed and estimated based on data gathered by the decision-makers in the context of a focus group. A comparison was made for the 6 suppliers and a 5-point scale was created to evaluate qualitative criteria and to transform the scores into quantitative values: 1 – Low; 2 – Below Average; 3 – Average; 4 – Good; 5 – Excellent. The values of the suppliers for each quantitative criterion were also normalized into this scale, so that all of them may be comparable as they have different units, and are identified in Chapter 4. For quantitative criteria, there is also a distinction between beneficial and non-beneficial criteria. This means that an increase in the beneficial criteria is positive for its score, while an increase in the non-beneficial criteria will negatively impact its final result, therefore each one is calculated according to a specific formula, detailed below.

The formula used to calculate the total score of each material-supplier option is based on the additive method and is represented by the following equation:

$$V(MSO) = \sum_{j=1}^{n} k_j \, v_j(MSO) \quad (3.2)$$

In which:

$V(MSO)$: Value of the material-supplier option (Total score)

$v_j(MSO)$: Partial value of the material-supplier option (Score of criterion *j*)

where $v_j\ (best\ x_j)$ = 5 and:

for Non-Beneficial Quantitative Criteria: $v_j(MSO) = \frac{Minimum\ (x_j)}{x_j} \times 5$

for Beneficial Quantitative Criteria: $v_j(MSO) = \frac{x_j}{Maximum\ (x_j)} \times 5$

where x_j: Data value of criterion *j*

k_j: Weight of criterion *j* in the normalized scale

n: Total number of criteria included in the set of criteria

Considering the final scores obtained, the highest score corresponding to the best material-supplier option will be selected to conduct a case study through a scenario-based analyzis.

3.3. Research step 3 – Case study: Scenario-based analyzis

Research step 3 comprises the case study that will focus on the best material-supplier option. Its sub-steps are schematized in Figure 3.3. This step begins with an introduction of the selected material-supplier option and its logistics context, defined as the baseline scenario. Afterwards, multiple scenarios will be created and defined for that logistics network context. Finally, results will be presented for each scenario.

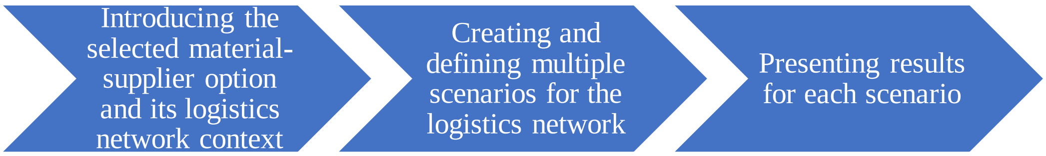

Figure 3.3 – Sub-steps of research step 3

Introducing the selected material-supplier option and its logistics network context

Research step 3 starts by introducing the selected material-supplier option, meaning introducing the supplier information, the material it provides, as well as its logistics network context in the country of origin. The MCDA for that material-supplier option will be defined as the baseline scenario, which will be then submitted to the creation of different scenarios by changing some of its standard characteristics.

Creating and defining multiple scenarios for the logistics network

At this stage, the logistics area will start entering the picture and play a meaningful role, since the best material-supplier option will be studied according to different scenarios of logistics networks, depending on its supply chain characteristics.

Aiming to reveal a practical application of sustainable packaging into a certain company's business context, this Thesis' theoretical basis can be practically applied through the analyzis of several different scenarios.

For the selected material-supplier option, multiple scenarios of logistics networks will be created, assuming different logistics perspectives – neutral, optimistic and pessimistic – considering the design of a new logistics network in which COMPANY A is the buying party, aiming to establish a new logistics network in Europe of the chosen material-supplier option. This research step will assume the form of a case study analyzis that will proceed with a sustainability evaluation.

Presenting results for each scenario

The evaluation of the impact on sustainability that each of the multiple scenarios may have will be conducted with the aid of KPIs in terms of economic and environmental impacts on sustainability performance, meanwhile considering the logistics performance. Three KPIs are used, namely Transportation Distance, Market Penetration and Product Traceability. These KPIs are based on the previous set of criteria used in the MCDA and are selected because they represent the most important changes in the performance impacts of the different logistics network scenarios, while reflecting the design of a new logistics network in which COMPANY A is the buying party aiming to establish the selected logistics network in Europe.

For Transportation Distance, each performance type is evaluated with one criterion from the MCDA: Shipping Costs (Economic), Waste generation quantities (Environmental) and Lead Time (Logistics). Market Penetration, as in the MCDA, is used to measure economic performance and Product Traceability is added to the framework, since it assumes a high importance to ensure the implementation a pallet recovery system based on CE. It will be developed a qualitative evaluation, based on the qualitative scale used in the MCDA, since it is easily comparable and measurable for these criteria.

3.4. Research step 4 – Solutions proposal

Finally, research step 4 concludes the methodology. It will first include an analyzis on the results obtained in research step 3, in order to develop conclusions, as represented in Figure 3.4. Moreover, solutions will be proposed to improve the performance of the logistics network analyzed.

Figure 3.4 – Sub-steps of research step 4

Analyzing the results obtained and developing conclusions

The last research step of the methodology begins with an analyzis of the results obtained in research step 3 for the case study. Based on the evaluation of the impact on sustainability and logistics performed in the scenario-based analyzis in research step 3, conclusions will be developed for each scenario.

Proposing solutions to improve the performance of the logistics network

Based on the conclusions that were developed, it is expected that different solutions will be achieved and proposed furtherly to the stakeholders involved in the selected logistics network.

The final overall analyzis of the different logistics network scenarios will be approached with a managerial perspective, so that different solutions can be proposed to the different stakeholders involved, always considering all aspects that should lead to a balanced decision aligned with the expectations of all of them.

These include the supplier, COMPANY A and other clients in the process of increasing the level of their supply chains of tertiary transport packaging products, in terms of economic and environmental sustainability and logistics performance. For this reason, this Thesis will impact the supply chain managerial area with a practical application within its business context.

4. Results Analyzis

4.1. Research step 1 – Scope definition and benchmarking

The following section introduces the results of the methodology implemented in this project. Firstly, the output of the benchmarking process contained in research step 1 is represented in *Annex A*. It corresponds to a sample of 8 companies, suppliers of tertiary transport packaging products (specifically pallets) with potential to be chosen for the case study, due to their characteristics, previously described in the methodology.

Regarding *Annex A*, it includes information of the type of material sold, type of packed product or industry related to the product and the location of each company (supplier).

Furthermore, after the benchmarking process, two different sub-sections are developed, including the data identified for the qualitative analyzis and analyzis of quantitative data performed, respectively.

4.1.1. Qualitative analyzis

The qualitative analyzis comprises a brief introduction on each company analyzed in the benchmarking process and then proceeds to evaluate their qualitative advantages and disadvantages. All the companies are analyzed from the point of view of their economic, environmental and social impact on sustainability, always considering their logistics performance. The data collected for the qualitative analyzis is presented in *Annex B*.

In *Annex B*, the data collected for each company is structured in accordance with the three pillars of sustainability and classified as an advantage or disadvantage of that company, relatively to its positive or negative impact on sustainability, respectively. In addition, each advantage and disadvantage of each company has a common advantage/disadvantage of another company attached, if there is one. This allows for a comparison of commonalities between companies regarding positive and negative factors of the logistics network. Moreover, details are presented in *Annex B* for the qualitative advantages and disadvantages that require a deeper description, therefore they are numbered to facilitate comprehension.

Yellow Pallet

Yellow Pallet (http://yellow-pallet.com) is a Dutch company established in 2012, that sells technology to produce transport pallets and blocks made of banana fiber. It supplies factories, that can produce pallets made of banana fiber blocks and wooden planks. The company develops the factory concept, as well as the harvesting model and arranges the setup of plantations if that is requested. It owns a production factory in Costa Rica.

CocoPallet International

CocoPallet International (https://www.cocopallet.com) is a Netherlands-based company that has adopted a CE approach and developed a sustainable and cost competitive export pallet made from coconut waste. Its pallets present great advantages for the transport of goods and for the environment. These are an alternative to replace timber pallets and prevent logging and transportation of millions of trees. The company is setting up facilities in South East Asia to supply Asian customers, as they need most pallets and have the least trees.

Bioestibas

Bioestibas (http://bioestibas.com) is a Colombian company that markets ecological pallets manufactured from highly polluting agricultural waste, with a high degree of innovation in its production process, achieving a product superior to that currently available on the market in terms of quality. It has built the first ecological pallet plant in Latin America, producing a fundamental product for packaging and logistics. Along with this innovative production, the company recycles an abundant quantity of waste in the territory, reducing the damages for the environment.

Biofiba

Biofiba (https://www.biofiba.com) is an Australian-based patented biocomposite simulated timber, used as a replacement for plastics, polystyrene, cardboard and as an alternative to timber. It is made from natural organic matter, from renewable non-food crops and resin and it has several uses within the export packaging industry. *Biofiba* extruded planks are fabricated into *biopallets*, using normal pallet assembly methods and machinery. The main raw material is industrial hemp, one of the oldest high strength natural fibers that exist.

Green Plastic Pallets

Green Plastic Pallets (https://www.greenplasticpallets.com) is a Minority-Owned, United States Government Contractor company specialized in the trade of fully American-made recycled plastic export pallets. The company strives to implement the vision and framework of the SPC. *Green Plastic Pallets* offers cost-effective solutions that meet specific product handling needs in the context of supply chains logistics.

Re>Pal

Re>Pal (https://re-pal.com) is an Australian company that uses state-of-the-art pallet technology to produce environmentally responsible pallets, fully made of waste plastic, which have a wide range of applications across business supply chains. Its main factory is located in East Java, Indonesia and the South East Asian export-hub and Australian region are its main markets.

CABKA_IPS

CABKA_IPS (https://cabka-ips.com/pt/en/m/plasticpallets/) is the leading company in recycled plastic pallets in Europe, with 7 factories, more than 150 products and 700 people working for sustainable solutions. The brand combines over 35 years of material, development and production expertise in all areas of plastics. They produce their products in Europe mainly in 3 factories, one in Germany, second one in Belgium and third one in Spain.

For Demand

For Demand (https://www.fordemand.pt/?lg=252) is a Portuguese company with its main activity based in the representation and commercialization of European manufactured products. Founded by 3 partners with professional experience in logistics, the company is specialized in the equipment area, storage material, maintenance, access and freight movement, protection and safety, office and mechanical workshops furniture. Its products include boxes and containers, transport and lifting equipment, pallets, among other logistics related equipment. The pallets products include hygienic pallets, wood fiber pallets and recycled plastic pallets, the ones to be analyzed in this section.

Results

After identifying advantages and disadvantages for each company (*Annex B*), a comparative analyzis is performed to identify common qualitative advantages and disadvantages among the sample of companies. On this matter, there are many advantages and disadvantages identified in more than one supplier.

Regarding the advantages, the most common among the sample of companies is shared by 7 out of 8 of them. It concerns the weight of the sustainable pallets, which are lighter than traditional wooden pallets, their strong capacity, nestable design, space efficiency due to stackability and also durability, with a longer average lifespan than wooden pallets. These characteristics are grouped in one advantage, that impacts not only the environmental but also the economic pillar of sustainability and is common to most of the companies. Moreover, the second most constant advantage is related to the product's biodegradability, recyclability and environmental friendliness, which are characteristics that positively impact environmental sustainability and are identified in 5 companies. Furthermore, two other advantages must be mentioned, each one recurrent in 4 companies. Firstly, there is a product and employee safety factor, common to the suppliers *Bioestibas*, *Green Plastic Pallets*, *Re>Pal* and *For Demand*. This advantage demonstrates that the companies ensure and are deeply concerned about *human health*, therefore it impacts all of the three pillars of sustainability. Moreover, the other advantage identified in 4 companies is the product suitability for multiple industries and applications, which is verified in *Biofiba*, *Green Plastic Pallets*, *Re>Pal* and *CABKA_IPS*. This advantage impacts the economic and social pillars of sustainability, since the product has a higher potential to generate revenue and is available for several different business sectors of the society.

On the other hand, concerning the disadvantages, the most frequent is the long transportation distance from the supplier's factories to Portugal. It poses an economic and environmental weakness for sustainability, due to high transport costs and environmental pollution and it is common to 6 out of 7 companies. In addition, all the 4 suppliers of recycled plastic pallets considered in the sample of companies demonstrate a drawback, which is the product's high initial investment and it has an economic impact on sustainability. Finally, 2 of the suppliers have products with limited suitability due to its material characteristics, namely *Yellow Pallet* and *CocoPallet International*, that sell banana and coconut-based pallets, appropriate only for the export of tropical fruits and dry products, respectively.

There are other common advantages beyond those mentioned, although they are recurrent mostly to 2 companies each, therefore they are not so meaningful. This qualitative analyzis demonstrates that there are less identifiable disadvantages than advantages among the companies. Moreover, there is evidence that the social pillar of sustainability is the less impacted one. Despite important commonalities verified, the analyzis is inconclusive regarding the selection of the best material-supplier option since the companies share an equilibrium in this evaluation.

4.1.2. Analyzis of quantitative data

The analyzis of quantitative data is expected to use KPIs of economic and environmental sustainability, as well as logistics performance of tertiary transport packaging products' suppliers, specifically pallet suppliers. As it was demonstrated by the qualitative analyzis, there is a low and meaningless impact of the suppliers' business on the social pillar of sustainability. Therefore, it will be disregarded in the analyzis of quantitative data, as well as 2 companies from the original sample, since it was not possible to conduct an interview. Moreover, the environmental pillar of sustainability is difficult to quantify, so it is implicit in some of the economic and logistics criteria used. The set of criteria and the respective definitions are structured in Table 4.1, as well as the type of criterion (economic sustainability or logistics performance). This set is defined according to the characteristics previously described in the methodology.

Table 4.1 – Analyzis of quantitative data: Set of criteria

Criteria	Definitions	Type of criterion
Unit Price	Price of a single product or service sold (Cambridge University Press, n.d.-a), in this case of a single pallet. Expressed in US dollars for the purpose of this analyzis of quantitative data.	Economic
Shipping Costs	Costs for the movement of cargo from Point A to Point B (Carnarius, 2016). Expressed in US dollars for the purpose of this analyzis of quantitative data.	Economic

Production Capacity	Production capacity is defined as maximum production or output, which can be produced in business with the help of available resources. The capacity is calculated over days or weeks or months (Bhasin, 2020). Converted to units per year for the purpose of this analyzis of quantitative data.	Logistics
Weight	The amount that something or someone weighs (Cambridge University Press, n.d.-b). In this analyzis of quantitative data, it refers to the amount, in kilograms, that one unit of a pallet weighs.	Logistics (and environmental)
Static Capacity	A static load rating refers to a pallet's non-varying load rating while the pallet is at rest, in this case the bottom pallet of the stack (Haynes, 2015). Expressed in kilograms for the purpose of this analyzis of quantitative data.	Logistics (and environmental)
Expected Lifetime	Product lifetime is the duration of the period that starts at the moment a product is released for use after manufacture and ends when it becomes obsolete beyond recovery (Den Hollander et al., 2017). Expressed in an average prediction in years for the purpose of this analyzis of quantitative data.	Logistics (and environmental)
Lead Time	The amount of time it takes from when a product is ordered to the moment when it is produced or received (My Accounting Course, n.d.). For the purpose of this analyzis of quantitative data, it is considered the moment when the product is received by the buyer and it is expressed in days.	Logistics

Results

The data collected for the analyzis of quantitative data is presented in *Annex C* and it was collected in interviews, as detailed in the methodology. Further details on the interviews are presented in *Annex C*. As initially described, it is clear that hardly any environmental aspect of sustainability is addressed in the quantitative data obtained within this set of criteria, as it was developed already predicting a difficulty for interviewees to quantify environmental-related data, which was confirmed. Despite that the impact on environmental sustainability is implicit within some criteria, namely for *Weight*, *Static Capacity* and *Expected Lifetime*, it is hard to develop meaningful conclusions based on the analyzis of quantitative data regarding the complete logistics network, namely considering the end-of-life treatments applied. Furthermore, not all interviewees disclosed information attributable to every criterion, therefore the analyzis is not balanced.

For this reason and based on the inconclusive results of the qualitative analyzis, a MCDA will be performed to decide on the best material-supplier option, meaning, the one with the highest impact on the economic and environmental pillars of sustainability, considering also the logistics performance. This analyzis will allow the comparison of multiple criteria used in both qualitative analyzis and analyzis of quantitative data, by using an improved, complete set of criteria that includes both qualitative and quantitative results, while addressing the whole logistics network process and the environmental impact on sustainability. Furthermore, for the criteria with missing data that was not disclosed by some companies, an estimation will be performed based on data gathered by the decision-makers in the context of a focus group.

4.2. Research step 2 – Material-supplier selection

4.2.1. Selecting and defining the set of criteria

The following set of criteria, structured in Table 4.2, was selected because it represents KPIs for evaluating the performance of each material-supplier option, in terms of its impact on economic and environmental sustainability, while also considering its logistics performance. It is based on the initial set of criteria used for the analyzis of quantitative data, but it is now complete with environmental criteria and one additional economic criterion. These were difficult to quantify for the analyzis of quantitative data, therefore a qualitative scale is used and afterwards normalized into quantitative values.

As previously stated, the social pillar of sustainability had a meaningless impact in the results of the qualitative analyzis, therefore it was disregarded in the analyzis of quantitative data, as it will be for the recreation of the set of criteria. For this reason, the set is divided in 3 main areas: economic, logistics and environmental criteria. The set of criteria is developed so that it can evaluate a logistics network along its entire process.

Table 4.2 – Multi-Criteria Decision Analyzis: Set of criteria

Criteria	Definitions	Type of criterion
EC1 – Unit Price	Price of a single product or service sold (Cambridge University Press, n.d.-a), in this case of a single pallet. Expressed in US dollars for the purpose of this MCDA.	Economic
EC2 – Shipping Costs	Costs for the movement of cargo from Point A to Point B (Carnarius, 2016). Expressed in US dollars for the purpose of this MCDA.	Economic
EC3 – Market Penetration	Measure of how much a product or service is being used by customers compared to the total estimated market for that product or service (Kenton, n.d.). Expressed in a 5-point scale for the purpose of this MCDA.	Economic
LO1 – Production Capacity	Production capacity is defined as maximum production or output, which can be produced in business with the help of available resources. The capacity is calculated over days or weeks or months (Bhasin, 2020). Converted to units per year for the purpose of this MCDA.	Logistics
LO2 – Weight	The amount that something or someone weighs (Cambridge University Press, n.d.-b). In this MCDA, it refers to the amount, in kilograms, that one unit of a pallet weighs.	Logistics
LO3 – Static Capacity	A static load rating refers to a pallet's non-varying load rating while the pallet is at rest, in this case the bottom pallet of the stack (Haynes, 2015). Expressed in kilograms for the purpose of this MCDA.	Logistics
LO4 – Expected Lifetime	Product lifetime is the duration of the period that starts at the moment a product is released for use after manufacture and ends when it becomes obsolete beyond recovery (Den Hollander et al., 2017). Expressed in an average prediction in years for the purpose of this MCDA.	Logistics
LO5 – Lead Time	The amount of time it takes from when a product is ordered to the moment when it is produced or received (My Accounting Course, n.d.). For the purpose of this MCDA, it	Logistics

	is considered the moment when the product is received by the buyer and it is expressed in days.	
EN1 – Number of End-of-Life treatments possible to apply	Amount of treatments that can be applied to a specific product that has exceeded its product lifetime and is no longer useful, in this case to a type of pallet. It includes Reuse, Recycle, Remanufacture, Return, Retain, Repair, Refurbish and Recover (Farooque et al., 2019). Expressed in a 5-point scale for the purpose of this MCDA.	Environmental
EN2 – Waste generation quantities	Estimation of the amount of waste generated during the production and shipping processes of the pallets (Disano, 2007). Expressed in a 5-point scale for the purpose of this MCDA.	Environmental
EN3 – Sustainable raw material sources	Classification based on the type of materials used in the production process of the pallets. Sustainable raw materials that can be extracted from natural, renewable resources such as trees and plants (Wageningen University & Research, n.d.) and that are biodegradable and/or recyclable are scored with higher values. Expressed in a 5-point scale for the purpose of this MCDA.	Environmental

Note: EC: Criteria with impact in economic sustainability; LO: Criteria with impact in logistics performance; EN: Criteria with impact in environmental sustainability.

4.2.2. Determining the relative weight of each criterion

This section contains the decision-making procedure of the swing weighting method and its results. The process starts by ranking the criteria in terms of importance (step 1) and quantifying the criteria (step 2), as represented in Figure 4.1.

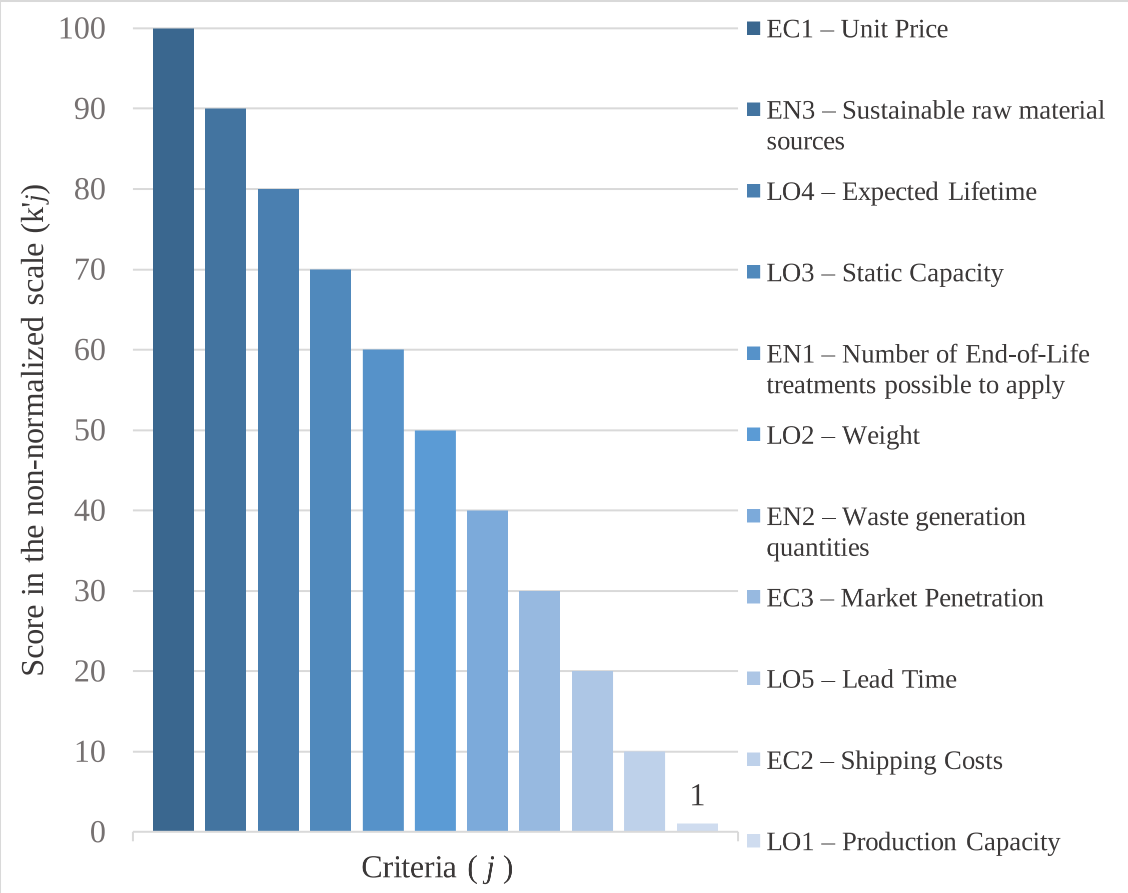

Figure 4.1 – Multi-Criteria Decision Analyzis: Ordered and quantified set of criteria

Furthermore, in step 3 (normalizing the values into weights), the non-normalized values are then normalized into weights, so that its sum equals to 100%. In Table 4.3, the answers are resumed with each criterion ordered, ranked with a non-normalized score and also its final normalized weight.

Table 4.3 – Multi-Criteria Decision Analyzis: Normalized set of criteria

Criteria (*j*)	**Type of criterion**	**Score of criterion *j* in the non-normalized scale (k'_j)**	**Weight of criterion *j* in the normalized scale (k_j)**
EC1 – Unit Price	Economic	k'_1 = 100	k_1 = 18.15%
EN3 – Sustainable raw material sources	Environmental	k'_{11} = 90	k_{11} = 16.33%
LO4 – Expected Lifetime	Logistics	k'_7 = 80	k_7 = 14.52%

LO3 – Static Capacity	Logistics	k'_6 = 70	k_6 = 12.70%
EN1 – Number of End-of-Life treatments possible to apply	Environmental	k'_9 = 60	k_9 = 10.89%
LO2 – Weight	Logistics	k'_5 = 50	k_5 = 9.07%
EN2 – Waste generation quantities	Environmental	k'_{10} = 40	k_{10} = 7.26%
EC3 – Market Penetration	Economic	k'_3 = 30	k_3 = 5.44%
LO5 – Lead Time	Logistics	k'_8 = 20	k_8 = 3.63%
EC2 – Shipping Costs	Economic	k'_2 = 10	k_2 = 1.81%
LO1 – Production Capacity	Logistics	k'_4 = 1	k_4 = 0.18%

4.2.3. Evaluating each material-supplier alternative and selecting the best one

After attaching a normalized weight to each criterion, it is possible to proceed with the MCDA. As represented in Figure 4.2, the criteria are divided in beneficial and non-beneficial ones, highlighted with green and red colors, respectively. This means that an increase in the beneficial criteria is positive for its score, while an increase in the non-beneficial criteria will negatively impact its final result.

		Yellow Pallet		Bioestibas		Green Plastic Pallets		Re>Pal		CABKA_IPS		For Demand	
Criteria (*j*)	**Weights (k*j*)**	**Data (x*j*)**	**Score (v*j* (*MSO*))**	**Data (x*j*)**	**Score (v*j* (*MSO*))**	**Data (x*j*)**	**Score (v*j* (*MSO*))**	**Data (x*j*)**	**Score (v*j* (*MSO*))**	**Data (x*j*)**	**Score (v*j* (*MSO*))**	**Data (x*j*)**	**Score (v*j* (*MSO*))**
EC1 – Unit Price	18.15%	$12.5	5	$27	2.31	$15,00	4.17	$17.50	3.57	$15*	4.17	€13.25 = $14.93	4.19
EC2 – Shipping Costs	1.81%	$3,000*	1.25	$5,000*	0.75	$2,486.90	1.51	$13,225.20	0.28	$1,000*	3.75	$750*	5
EC3 – Market Penetration	5.44%	Average	3	Below Average	2	Good	4	Average	3	Good	4	Below Average	2
LO1 – Production Capacity	0.18%	1,000,000 units/year	1.67	504,000 units/year	0.84	3,000,000 units/year*	5	1,000,000 units/year*	1.67	2,000,000 units/year*	3.33	300,000 units/year*	0.5
LO2 – Weight	9.07%	15.0kg*	2.33	18 - 25kg (Average = 21.5kg)	1.63	7.7kg	4.55	19.5kg	1.79	5.0 - 9.0kg (Average = 7.0kg)	5	7.0kg	5
LO3 – Static Capacity	12.70%	2,000kg	2.33	4,300kg	5	2,268kg	2.64	3,000kg	3.49	1,600 - 3,000kg (Average = 2,300kg)	2.67	2,000kg	2.33
LO4 – Expected Lifetime	14.52%	7.5 years*	3	7.5 years*	3	10 years	4	10 - 15 years (Average = 12.5 years)	5	10 years*	4	10 years*	4
LO5 – Lead Time	3.63%	18 days*	1.94	20 days*	1.75	17 days*	2.06	28 days (20 business days)*	1.25	7 days*	5	14 days	2.5
EN1 – Nº of End-of-Life treatments possible to apply	10.89%	Average	3	Average	3	Excellent	5	Good	4	Below Average	2	Below Average	2
EN2 – Waste generation quantities	7.26%	Good	4	Good	4	Good	4	Good	4	Below Average	2	Average	3
EN3 – Sustainable raw material sources	16.33%	Good	4	Good	4	Average	3	Average	3	Average	3	Average	3
Total Score (V(*MSO*))	**99.98% = 100%**	**-**	**3.38**	**-**	**3.10**	**-**	**3.74**	**-**	**3.41**	**-**	**3.46**	**-**	**3.31**

Figure 4.2 – Multi-Criteria Decision Analyzis: Results

Scale: 1 – Low; 2 – Below Average; 3 – Average; 4 – Good; 5 – Excellent

*Non-disclosed data by the companies, estimated for the purpose of this MCDA due to lack of information.

The MCDA performed with the aid of the weights obtained through the swing weighting method indicated that *Green Plastic Pallets*, the American supplier of recycled plastic pallets, has the highest total score of 3.74, as highlighted with green color in Figure 4.2.

Although, in order to confirm the accuracy of this result, a sensitivity analyzis is performed. It will determine the impact that a negative change in the values of some criteria can have on the result obtained. For this purpose, 3 scenarios are created for the data values of the supplier *Green Plastic Pallets* and the respective changes in the scores are represented in Table 4.4.

Table 4.4 – Multi-Criteria Decision Analyzis: Sensitivity analyzis

Scenarios	New Total Score					
	Yellow Pallet	**Bioestibas**	**Green Plastic Pallets**	**Re>Pal**	**CABKA _IPS**	**For Demand**
1. EC1 – Unit Price increases by 50%	-	-	3.49 (-0.25)	-	-	-
2. LO1 – Production Capacity decreases by 50%	-	-	-	-	-	-
3. LO5 – Lead Time increases by 50%	-	-	3.71 (-0.03)	-	-	-

The scenarios are chosen due to the volatility of their correspondent criteria. In this case, Unit Price, Production Capacity and Lead Time are the most likely criteria to suffer changes within a business context.

Regarding the Unit Price of *Green Plastic Pallets* (scenario 1), an increase of 50% would mean a decrease of 0.25 points in the company's total score, since it reflects an increase in a non-beneficial criterion. For this reason, and since the minimum reference value for this criterion does not change, only *Green Plastic Pallets* has its score affected. Nevertheless, such considerable price increase would still maintain the company's highest total score (3.49), although it would approximate it to *CABKA_IPS's* total score of 3.46.

Moreover, a decrease of 50% in the Production Capacity of *Green Plastic Pallets* (scenario 2) would not represent any change for the total score of any company. This is due to the fact that the weight assigned to this criterion is extremely low (0.18%), therefore insignificant for the total score. Despite being a beneficial criterion and considering the decrease of 50% (from 3,000,000 to 1,500,000 units/year), which would turn the Production Capacity of *CABKA_IPS* into the new maximum reference value (2,000,000 units/year) with a score of 5, meanwhile increasing the score of the other companies, the criterion's relevance is too small to create any change in the total values.

Finally, in scenario 3, it is assumed that the Lead Time increases by 50%, which is also a non-beneficial criterion as the Unit Price, therefore it follows the same explanation for no changes in other companies' scores. The score of *Green Plastic Pallets* would reduce only by 0.03 points to a new total score of 3.71.

In conclusion, any hypothetical negative change that may occur in the volatile criteria of *Green Plastic Pallets* is not likely to change the company with the highest total score. Only a sudden and significant increase in the Unit Price would considerably impact the total score, as it is the most relevant weight in the MCDA.

Therefore, it can be concluded that *Green Plastic Pallets* is the most appropriate material-supplier option between all the alternatives, when considering the set of the criteria used in the analyzis.

4.3. Research step 3 – Case study: Scenario-based analyzis

After the implementation of the MCDA, the supplier *Green Plastic Pallets* was the chosen one to proceed with the logistics network design. In this context, recycled plastic is the type of material to be analyzed in this case study.

4.3.1. Introducing the selected material-supplier option and its logistics network context

As previously described, *Green Plastic Pallets* is a company from the United States of America, specialized in the trade of fully American-made recycled plastic pallets. *Green Plastic Pallets* offers cost-effective solutions that meet specific product handling needs in the context of supply chains logistics. The logistics network to be analyzed is the one focused on the recycled plastic pallets, a product of *Green Plastic Pallets* company, sold across the USA.

This section introduces the conditions for the creation of a logistics network in which COMPANY A is the buying party, aiming to establish a new logistics network in Europe, which is considered as the baseline scenario in this case study. Starting to present the existing logistics network cycle of *Green Plastic Pallets* in the USA (Figure 4.3) from the raw material sourcing, the company uses fully American-made recycled High-Density Polyethylene (HDPE), which is a type of commonly produced plastic, easily recyclable and it helps keeping non-biodegradable waste out of landfills. The production process is performed by manufacturers taking the lead in post-industrial users of plastic in the United Stated of America (USA), benefiting from used plastic parts. Moreover, it is implemented injection mould technology – a manufacturing process commonly used for producing parts in large volume, in which the price tends to drop strongly as more parts are produced – that matches with the company's large production capacity. At the end of the product's lifetime, there are a lot of end-of-life treatments possible to apply which will be furtherly described, but recycling is the most common one. The company implements a buy-back programme, in which it buys back the non-serviceable pallets to their customers, to recycle them and start the logistics network cycle all over again.

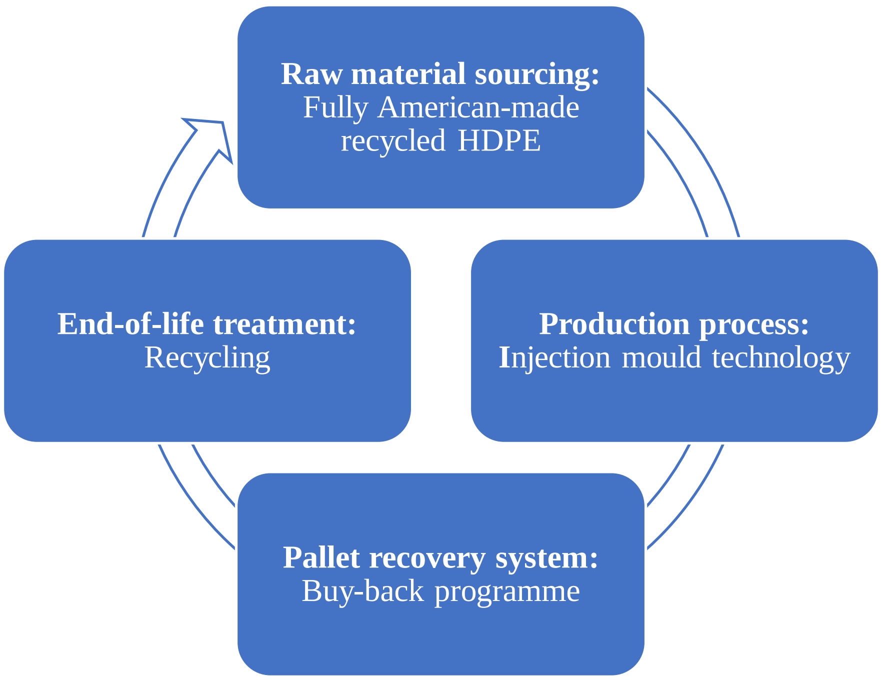

Figure 4.3 – Scenario-based analyzis: Logistics network cycle of Green Plastic Pallets in the USA

Based on this introduction, it is important to analyze the performance of the baseline scenario, in which COMPANY A is the buying party, aiming to establish a new logistics network in Europe. Tracing back to the MCDA performed, this analyzis is performed considering the company's scores obtained for each criterion, presented in Table 4.5, as these form a basis for the set of KPIs that will be used to evaluate each scenario designed for the logistics network. The qualitative analyzis and analyzis of quantitative data constitute a basis for this analyzis and all the quantitative scores of the MCDA are normalized to the qualitative scale previously used.

Table 4.5 – Scenario-based analyzis: Performance evaluation of the baseline scenario

Criteria (j)	**Data (x_j)**	**Score ($v_j(MSO)$)**
EC1 – Unit Price	\$15	4.17 = Good
EC2 – Shipping Costs	\$2,486.90	1.51 = Below Average
EC3 – Market Penetration	Good	4
LO1 – Production Capacity	3,000,000 units/year*	5 = Excellent
LO2 – Weight	7.7kg	4.55 = Excellent
LO3 – Static Capacity	2,268kg	2.64 = Average
LO4 – Expected Lifetime	10 years	4 = Good
LO5 – Lead Time	17 days*	2.06 = Below Average
EN1 – Number of End-of-Life treatments possible to apply	Excellent	5
EN2 – Waste generation quantities	Good	4
EN3 – Sustainable raw material sources	Average	3

* Non-disclosed data by the companies, estimated for the purpose of this MCDA due to lack of information.

Regarding economic criteria and starting with Unit Price, the company obtained a score of 4.17, corresponding to “Good” on the qualitative scale among the sample of companies. Although, recycled plastic pallets represent a high initial investment, 75% higher than traditional wooden pallets, as described in the qualitative analyzis and this is a drawback to consider in the performance analyzis. Nevertheless, it reflects a low total operating cost – after 10 pallet trips, the cost per trip is significantly lower than that of a wooden pallet. As for Shipping Costs, the company achieved its worst score among the set of criteria, since the company is located in the USA and it is costly to bring the products to Portugal, if a logistics network is to be created here, which is furtherly covered in the scenario creation. This is both an economic and environmental disadvantage, as it is presented in the qualitative analyzis.

Moreover, *Green Plastic Pallets* demonstrated a "Good" Market Penetration on the qualitative scale, which is linked to its huge Production Capacity, rated with a score of 5, since it is the best rated company on this criterion. Both scores are related to the fact that the company supplies one of the major American multinational retail corporations.

Concerning Weight, the company has one of the highest scores, since recycled plastic pallets are lightweight, which means a lower fuel consumption in transportation and consequently a lower economic and environmental impact. Another logistics criterion is Static Capacity, for which the company has an "Average" score of 2.64, reflecting a medium load capacity of the pallets. The higher the capacity, the lower the number of required trips to transport a certain quantity of products, therefore it affects economic and environmental performance, besides the logistics. With respect to the Expected Lifetime of the pallets, 10 years means a "Good" score because the pallet is durable and represents a benefit for economic and environmental performance. As represented in Table 4.5, *Green Plastic Pallets* evidences a Lead Time "Below Average", with a score of 2.06. This is related to the long transportation distance and follows the same explanation as for Shipping Costs.

Finally, regarding environmental criteria, the company demonstrates an "Excellent" score for the number of end-of-life treatments possible to apply. Despite that recycling is the most used one, there are a lot of possibilities namely reusing, remanufacturing and returning. The latter is particularly meaningful, since the company implements a policy of buying back the pallets that are no longer useful, contributing actively for the implementation of a CLSC. With reference to waste generation quantities, a "Good" score is achieved because of low quantities of waste generated in both production and end-of-life processes. Last but not least, the company is within the average such as other recycled plastic pallets suppliers, concerning the sustainable raw material sources, as there are other material options that are natural and biodegradable.

4.3.2. Creating and defining multiple scenarios for the logistics network

The recycled plastic pallets logistics network of *Green Plastic Pallets* will now be analyzed assuming different scenarios that could occur, by changing some processes in this CLSC. The scenarios are built considering COMPANY A in the process, as the buying party and three scenarios are created – neutral, optimistic and pessimistic – considering whether it is possible to fulfill the objective of establishing a logistics network in Europe.

Scenario A: Establishing a USA-Europe logistics network (Neutral Scenario)

Firstly, scenario A is created as a neutral scenario, in which a new logistics network is designed, from the USA to Europe and vice versa. This scenario is divided in two sub-scenarios. As represented in Figure 4.4 for scenario A1, COMPANY A buys the product to *Green Plastic Pallets* and ships it to Portugal. Moreover, the company resells the product across Europe to potential customers. In the contract of sale, the buying company agrees on a buy-back contract, to sell the pallets to COMPANY A at the end of the product's lifetime, by the HDPE price.

For this specific scenario, it is assumed that the pallets are recycled in Europe and then the recycled materials are sold and shipped back so that *Green Plastic Pallets* can remanufacture the product again in the USA, restarting the cycle.

- **A1:** Pallets are recycled in Europe and then remanufactured in the USA

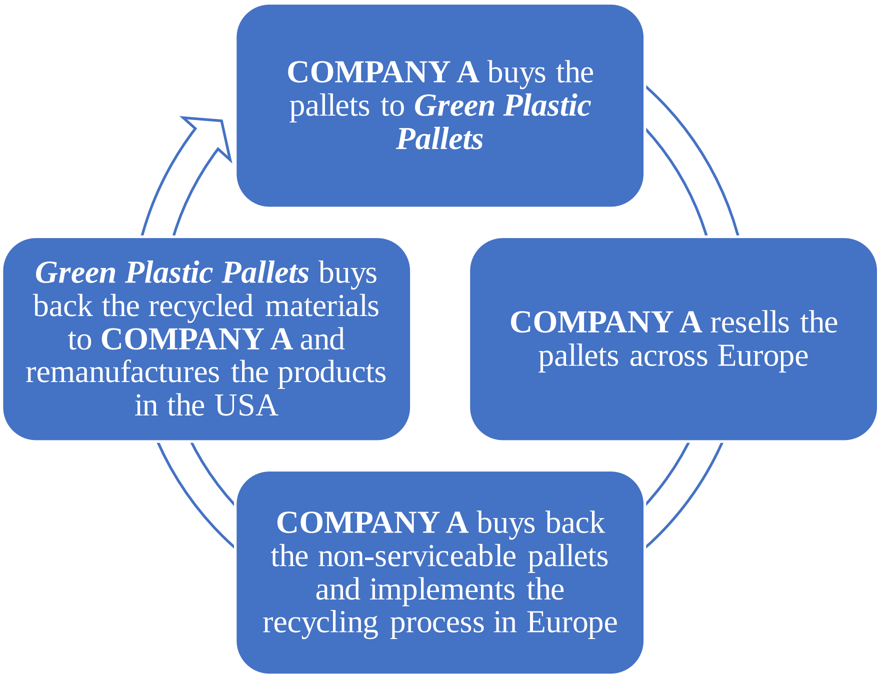

Figure 4.4 – Scenario-based analyzis: Logistics network cycle of scenario A1

As for scenario A2 (Figure 4.5), the structure is the same as in A1, but it is assumed that the non-serviceable pallets are sold right away to *Green Plastic Pallets* to be recycled and remanufactured in the USA.

- **A2:** Pallets are recycled and remanufactured in the USA

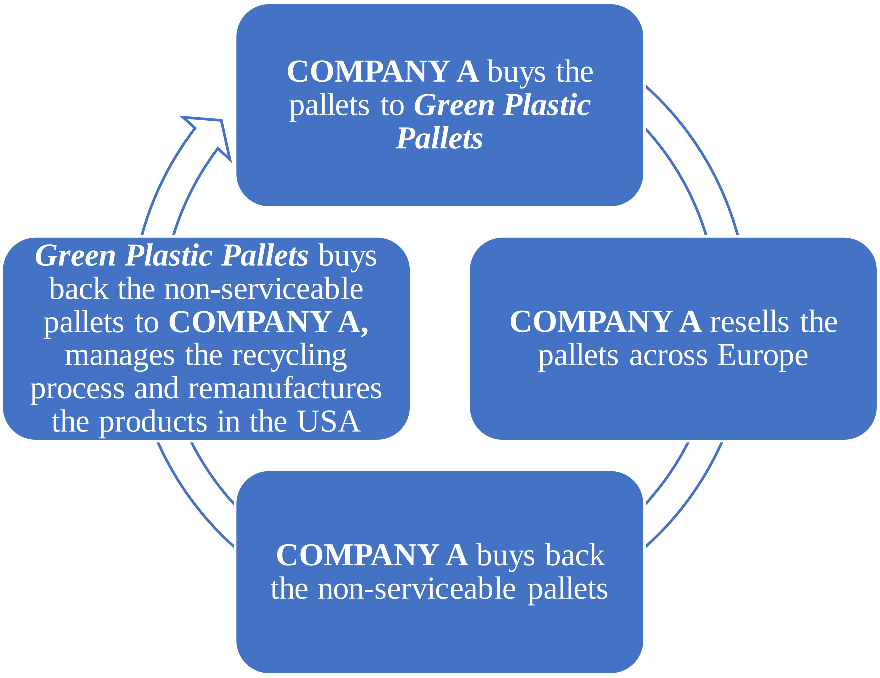

Figure 4.5 – Scenario-based analyzis: Logistics network cycle of scenario A2

Scenario B: Establishing a logistics network in Europe (Optimistic Scenario)

In scenario B (Figure 4.6), an optimistic perspective is considered, supposing that it is possible to fulfill the objective of establishing a logistics network in Europe. It is assumed that importing the pallets is viable for COMPANY A to continue the CLSC in Europe. In this case, COMPANY A will be responsible for all the processes in the logistics network. After buying the pallets and reselling them across Europe like in previous scenarios, the company buys back the product and is responsible for its end-of-life treatment, as well as for restarting the production process in Europe. The company would be responsible for continuing the selling process in the European market.

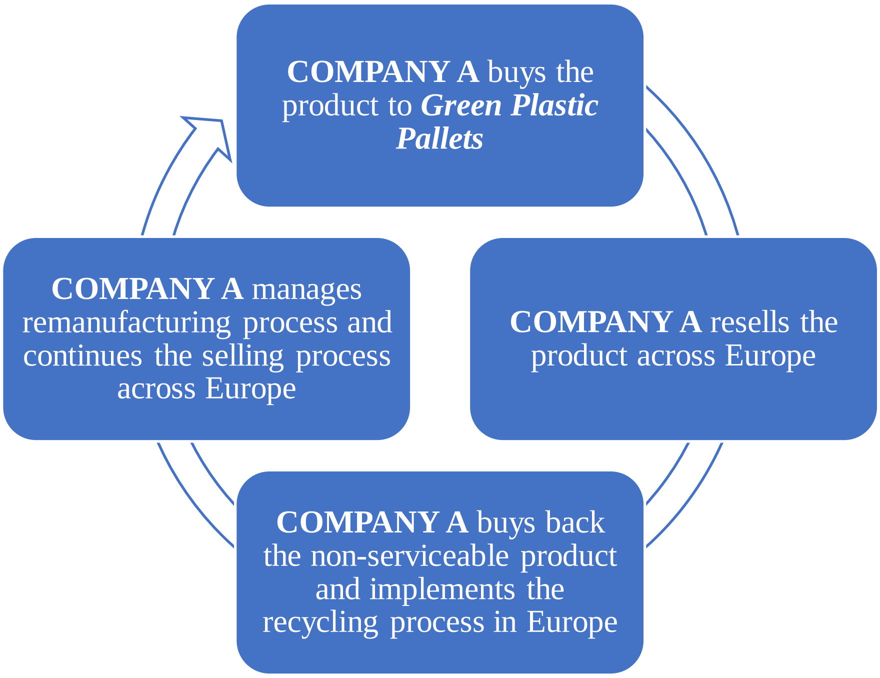

Figure 4.6 – Scenario-based analyzis: Logistics network cycle of scenario B

Scenario C: Establishing a logistics network in the USA (Pessimistic Scenario)

Lastly, in scenario C (Figure 4.7), a pessimistic perspective is considered, taking for granted that it is not possible to implement a logistics network in Europe. In this case, it is assumed that importing the pallets is not viable in the perspective of COMPANY A. Although, it would be possible to establish a partnership in which COMPANY A is responsible for maintaining the closed-loop system in the USA. The company buys the product as in previous scenarios, although there is no shipment process to Portugal.

COMPANY A can resell the product to clients across the USA, but it has the responsibility to find recycling companies in the USA and managing the end-of-life process, by keeping a constant track on the product. Finally, it provides the recycled materials to *Green Plastic Pallets* that will be used on the remanufacturing process.

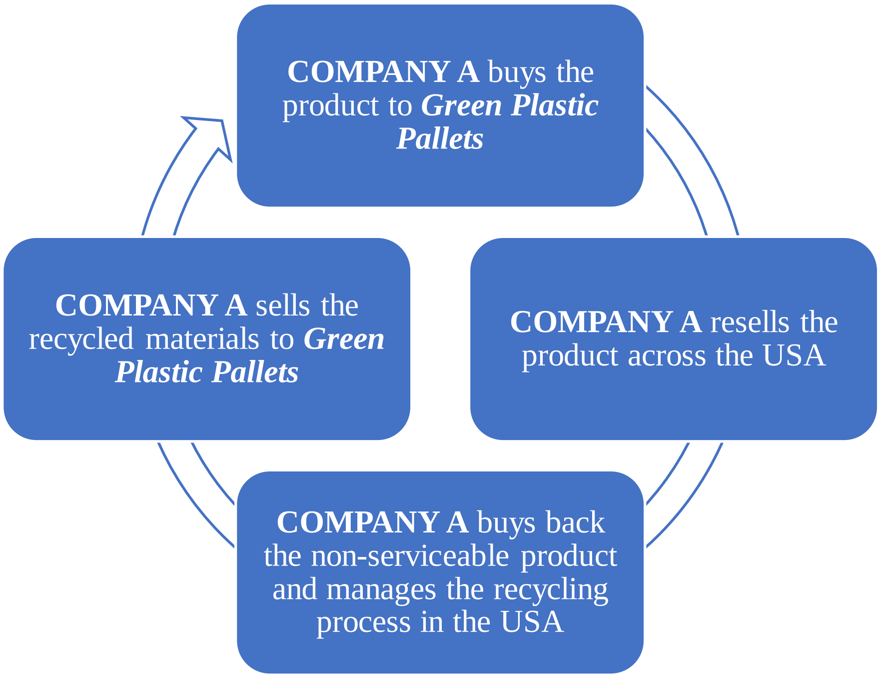

Figure 4.7 – Scenario-based analyzis: Logistics network cycle of scenario C

4.3.3. Presenting results for each scenario

The performance evaluation for each scenario is based on some criteria of the set of criteria used for the MCDA, as explained in the methodology, and will be denominated as KPIs for this analyzis. Three KPIs are used, namely Transportation Distance, Market Penetration and Product Traceability. Each scenario is evaluated based on the three KPIs, that in case of Transportation Distance impacts all of the 3 types of performance, as represented in Table 4.6. For this criterion, each performance type is evaluated with one criterion from the MCDA: Shipping Costs, Waste generation quantities and Lead Time. Market Penetration, as in the MCDA, is used to measure economic performance and Product Traceability is added to the framework, since it assumes a high importance to ensure the implementation of the pallet recovery system based on CE. The evaluation of each scenario is measured with the MCDA qualitative scale.

Table 4.6 – Scenario-based analyzis: Performance evaluation of the alternative scenarios

Scenario		KPIs	Economic Sustainability Performance	Environmental Sustainability Performance	Logistics Performance
A	A1	Transportation Distance	Shipping Costs: Low	Waste generation quantities: Low	Lead Time: Below Average
		Market Penetration	Excellent	-	-
		Product Traceability	-	Below Average	Average
	A2	Transportation Distance	Shipping Costs: Low	Waste generation quantities: Below Average	Lead Time: Average
		Market Penetration	Excellent	-	-
		Product Traceability	-	Below Average	Average
B		Transportation Distance	Shipping Costs: Below Average	Waste generation quantities: Good	Lead Time: Good
		Market Penetration	Good	-	-
		Product Traceability	-	Good	Excellent
C		Transportation Distance	Shipping Costs: Excellent	Waste generation quantities: Excellent	Lead Time: Excellent
		Market Penetration	Average	-	-
		Product Traceability	-	Low	Below Average

4.4. Research step 4 – Solutions proposal

4.4.1. Analyzing the results obtained and developing conclusions

Scenario A1:

The performance levels of the first scenario demonstrate low economic performance based on transportation distance KPI. This is due to the fact that the product is shipped to Portugal, sold across Europe and shipped back to the USA, meaning that waste generation quantities of shipping process are also high, achieving a low environmental performance. Although, the product market penetration is likely to achieve great performance levels, because it is implemented consecutively in both markets.

Scenario A2:

Scenario A2 differs from scenario A1 in the environmental sustainability and logistics performance, with a slightly higher performance due to less waste generation quantities and a lower lead time. This is verified because the end-of-life treatment is performed in the USA, meaning that there is no extra transportation distance of the product to the recycling center in Portugal.

Scenario B:

Scenario B, as an optimistic one, fulfills the objective of establishing a continuous logistics network in Europe by assuming it is viable for COMPANY A. In fact, it would be costly to ship the products to Portugal as verified in scenario A, although not so costly because the product does not return to the USA. COMPANY A can establish a partnership with a third-party, waste management company to deal with the recycling process on a continuous basis in Europe. In this scenario there is an increased product market penetration, considering the product launch in the European market. Above all, it is verified that product traceability achieves the highest performance levels in this scenario, because COMPANY A can easily manage the product status in the European market.

Scenario C:

In scenario C, the product is not shipped outside the USA, therefore the shipping costs are reduced, and the economic performance is excellent concerning the transportation distance KPI. Consequently, waste generation quantities and lead time will also achieve higher levels of performance in comparison with the remaining scenarios. The market penetration of the product would maintain its average levels within the USA market.

Although, it would be harder to keep a track on the product during its lifetime, as COMPANY A would be managing the whole process from Portugal.

All in all, it is clear that every scenario ensures the implementation of a pallet recovery system, which is crucial for the establishment of a CLSC. With higher or lower impact on market penetration or transportation distance KPIs, product traceability assumes the highest importance for keeping the stakeholders updated on the logistics process and specially on when to proceed with the end-of-life treatment, determinant for the environmental performance levels and waste minimization.

4.4.2. Proposing solutions to improve the performance of the logistics network

Based on the performance evaluation of the logistics network's scenarios, some recommendations are presented in this section.

It is proposed the creation of a digital database, that promotes a constant data share by every stakeholder that is involved in the pallets' logistics network, reflecting the product's status during its different lifecycles. This digital database would contain a directory with contacts of all the clients that bought the pallets and its responsibilities on the process.

Furthermore, a creation of a QR code system is proposed, attached to the product, so that every stakeholder can introduce this meaningful information of the pallets and trace its footprint, which is constantly updated on the digital database. Namely, all the product specifications and current physical status, but most importantly information regarding the supplier, the buyer and a third-party company that is responsible for the management of the end-of-life treatment, in this case the recycling process. This information follows the next recommendation, in which each entity involved in the process is liable for a certain aspect of the logistics network process to ensure environmental sustainability. Each entity having its own "environmental accountability" on the process:

- Supplier – Has or has not presented the buyer with an option to recycle the product;
- Buyer: Has or has not decided to deliver the non-serviceable product for recycling to the third-party company, at the end of its lifetime;
- Third-party company: Has or has not dealt with the recycling process of the product

The supplier is liable for preparing the recycling process, pre-hiring the services of a third-party and covering its costs, previously to the moment of sale, as well as for presenting the buyer with details on how to proceed after the product's lifetime. The buyer is accountable for starting the recycling process, according to the guidelines provided by the supplier. Moreover, a recycling entity assumes the role of a third-party, responsible for the recycling process.

This information is available for the users of the pallet, who can trace all the stakeholders involved in the process and if they fulfilled their duties. If the product is found to be disposed, public waste management companies (acting by the state) can trace product's information and charge the supplier, the buyer, or even the third-party according to its "environmental accountability" for the product.

If the buying company intends to recycle the pallets itself and then remanufacture them, ensure that the buying company takes care of the treatment at product's end-of-life to the continue the closed-loop process, by keeping track on the product (ask for contractual proof that treatment was applied). If the buying company rejects/does not comply, charge a fee in addition to the product's unit price at the moment of sale.

This is valid for all the scenarios designed, in which the stakeholders are *Green Plastic Pallets*, COMPANY A and the further clients in Europe or in the USA, depending on the scenario.

5. Conclusion

As per the literature review, there is evidence for a growing need to integrate both concepts of FL and RL, to create a CLSC based on the CE. The LE is an unsustainable model of resource utilization in the long-run and it must be adapted into a circular one, in which waste in minimized. The literature also provides that the process of developing sustainable transport packaging solutions is an example of a complete logistics network design. The development of such logistics context requires the involvement and commitment of several stakeholders in the end-to-end supply chain, considering that a CE model should be achieved through the inclusion of stakeholders such as recyclers and waste contractors into the process.

Therefore, and as evidenced in the findings of the scenario-based analyzis, product traceability assumes a meaningful role in logistics network design, specially to ensure that each entity involved has fulfilled its duty during and after the product lifetime. It is also proved that social sustainability is the less addressed pillar in the literature, and in the qualitative analyzis of this Thesis it was the most difficult one to measure.

COMPANY A's challenge of constantly sourcing more and more sustainable ways of achieving its final products, specifically by avoiding waste generated by transport packaging solutions, triggered the need for the design of logistics networks, based on the Circular Economy, that can promote an adequate end-of-life treatment for each of these products. The sample of potential suppliers analyzed demonstrated an increasing trend for the use of natural materials as mixed inputs in wooden pallet production processes, as a sustainable and biodegradable alternative to common wooden pallets. Nevertheless, recycled plastic pallets are a solid alternative as they weigh less and last longer than common and natural wooden pallets. Most importantly, they are suitable for all types of industry, which is a drawback in wooden pallets produced from natural materials with specific characteristics that limit their export compliance only to products such as tropical fruits or dry products.

As for limitations of this Thesis and guidelines for future research, the qualitative analyzis, analyzis of quantitative data and Multi-Criteria Decision analyzis should be extended to a wider sample of companies. A database gathered from a larger number of tertiary transport packaging suppliers, specifically sustainable pallets, would enable a more complete comparison of all the scores obtained for each KPI and consequently increase the reliability of the results. Furthermore, the sample of companies should include suppliers located on different geographical areas than those selected, preferably with different logistics network characteristics. Moreover, the social pillar of sustainability should be analyzed with more detail for each company in the qualitative analyzis and if possible, it should be extended to the analyzis of quantitative data, MCDA and scenario-based analyzis. The set of scenarios can also be enlarged, by applying different changes in logistics aspects.

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Annexes

Annex A – Benchmarking: Sample of companies

Companies (Suppliers)	Type of Material used in Pallets	Type of Packed Product/Industry	Location
1. Yellow Pallet	• Banana Fiber Blocks • Wood	Tropical Fruit (bananas, pineapple, melons) and other products	Netherlands (Production facility in Costa Rica)
2. CocoPallet International	• Coconut Waste (Husk) • Natural Fibers and Lignin	• Single Use • One Way • Preferably Full Load Exports • Dry Products (e.g. Books, textiles, etc.) • Preferably in boxes	Netherlands (Exports to Asia)
3. Bioestibas	Floricultural waste (hydrangea stems)	Industrial use - B2B (fire resistant)	Colombia
4. Biofiba	(Industrial) Hemp – Biodegradable	B2B (Multiple industries and applications e.g. Food)	Australia
5. Green Plastic Pallets	Recycled Plastic	Industrial use (Including Pharmaceuticals, Food & Beverages)	USA
6. Re>Pal	Recycled Plastic	Industrial use (Including Pharmaceuticals, Food & Beverages)	Australia
7. CABKA_IPS	Recycled Plastic	Industrial use (Including Pharmaceuticals, Food & Beverages)	Germany, Belgium, Spain, USA
8. For Demand	Recycled Plastic	Industrial use (Including Pharmaceuticals, Food & Beverages)	Portugal

Annex B – Qualitative analyzis: Data collection – Common advantages and disadvantages among the sample of companies

<table>
<tr><th>Company</th><th rowspan="2">Pillars of Sustainability</th><th colspan="2">Advantages</th><th colspan="2">Disadvantages</th></tr>
<tr><th>(Supplier)</th><th>Individually</th><th>Commonly</th><th>Individually</th><th>Commonly</th></tr>
<tr><td rowspan="12">1. Yellow Pallet</td><td rowspan="10">a) Economic</td><td rowspan="2">1.1. Cost-effective transport pallets</td><td>CocoPallet International (2.1.)</td><td rowspan="5">1.7. Transport costs of long transportation distance from Costa Rica to Portugal</td><td>CocoPallet International (2.9.)</td></tr>
<tr><td>Bioestibas (3.1.)</td><td>Bioestibas (3.9.)</td></tr>
<tr><td>1.2. Productive banana plantations</td><td>-</td><td>Biofiba (4.6.)</td></tr>
<tr><td rowspan="6">1.3. Pallets are lighter than wooden pallets</td><td>CocoPallet International (2.4.)</td><td>Green Plastic Pallets (5.9.)</td></tr>
<tr><td>Bioestibas (3.3.)</td><td>Re>Pal (6.7.)</td></tr>
<tr><td>Green Plastic Pallets (5.1.)</td><td rowspan="5">1.8. Limited suitability</td><td rowspan="5">CocoPallet International (2.11.)</td></tr>
<tr><td>Re>Pal (6.1.)</td></tr>
<tr><td>CABKA_IPS (7.1.)</td></tr>
<tr><td>For Demand (8.2.)</td></tr>
<tr><td>1.4. Local employment</td><td>CocoPallet International (2.6.)</td></tr>
<tr><td rowspan="2">b) Environmental</td><td rowspan="2">1.3. Pallets are lighter than wooden pallets</td><td>CocoPallet International (2.4.)</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Bioestibas (3.3.)</td></tr>
</table>

			Green Plastic Pallets (5.1.)		
			Re>Pal (6.1.)		CocoPallet International (2.9.)
			CABKA_IPS (7.1.)		Bioestibas (3.9.)
			For Demand (8.2.)	1.7. Environmental impact of long transportation distance from Costa Rica to Portugal	Biofiba (4.6.)
		1.5. Low harmful emissions during manufacturing process	Biofiba (4.5.)		Green Plastic Pallets (5.9.)
			Re>Pal (6.5.)		Re>Pal (6.7.)
		1.6. Biodegradable pallets	CocoPallet International (2.7.)		
			Bioestibas (3.5.)		
			Green Plastic Pallets (5.5.)		
			For Demand (8.5.)		
	c) Social	1.4. Local employment	CocoPallet International (2.6.)	1.8. Limited suitability	CocoPallet International (2.11.)
2. CocoPallet International	a) Economic	2.1. Low cost	Yellow Pallet (1.1.)	2.9. Facilities located at a long distance: South East Asia	Yellow Pallet (1.7.)
			Bioestibas (3.1.)		Bioestibas (3.9.)
		2.2. Customizable	Biofiba (4.2.)		Biofiba (4.6.)
		2.3. Moisture resistant	Bioestibas (3.2.)		Green Plastic Pallets (5.9.)
			Yellow Pallet (1.3.)		Re>Pal (6.7.)

			Bioestibas (3.3.)	2.10. One-way, single use pallets	-
		2.4. Strong capacity, nestable and lightweight	Green Plastic Pallets (5.1.)	2.11. Pallet suitability is limited, only allows the transportation of dry products: books, textiles, etc.	Yellow Pallet (1.8.)
			Re>Pal (6.1.)		
			CABKA_IPS (7.1.)		
			For Demand (8.2.)		
		2.5. Certified for international shipment – Phytosanitary concerns: ISPM 15	Green Plastic Pallets (5.3.)		
		2.6. Extra income for local farmers	Yellow Pallet (1.4.)		
		2.8. Insect-free, flame retardant *(human health)*	Bioestibas (3.7.)		
	b) Environmental	2.4. Strong capacity, nestable and lightweight	Yellow Pallet (1.3.)	2.9. Facilities located at a long distance: South East Asia	Yellow Pallet (1.7.)
			Bioestibas (3.3.)		Bioestibas (3.9.)
			Green Plastic Pallets (5.1.)		Biofiba (4.6.)
			Re>Pal (6.1.)		Green Plastic Pallets (5.9.)
			CABKA_IPS (7.1.)		Re>Pal (6.7.)
			For Demand (8.2.)	2.10. One-way, single use pallets	-

		2.5. Certified for international shipment – Phytosanitary concerns: ISPM 15	Green Plastic Pallets (5.3.)		
		2.7. Fully bio-based and circular	Yellow Pallet (1.6.)		
			Bioestibas (3.5.)		
			Green Plastic Pallets (5.5.)		
			For Demand (8.5.)		
		2.8. Insect-free, flame retardant *(human health)*	Bioestibas (3.7.)		
	c) Social	2.6. Extra income for local farmers	Yellow Pallet (1.4.)	2.11. Pallet suitability is limited, only allows the transportation of dry products: books, textiles, etc.	Yellow Pallet (1.8.)
		2.8. Insect-free, flame retardant *(human health)*	Bioestibas (3.7.)		
3. Bioestibas	a) Economic	3.1. Price/efficiency ratio	Yellow Pallet (1.1.)	3.9. Long transportation distance from Colombia	Yellow Pallet (1.7.)
			CocoPallet International (2.1.)		CocoPallet International (2.9.)
		3.2. Moisture resistance	CocoPallet International (2.3.)		Biofiba (4.6.)
		3.3. Low weight, space efficiency and stackability	Yellow Pallet (1.3.)		Green Plastic Pallets (5.9.)
			CocoPallet International (2.4.)		Re>Pal (6.7.)

			Green Plastic Pallets (5.1.)		
			Re>Pal (6.1.)		
			CABKA_IPS (7.1.)		
			For Demand (8.2.)		
		3.4. Product superior to traditional wood pallet, with a high degree of innovation	-		
		3.7. Fire resistance *(human health)*	CocoPallet International (2.8.)		
		3.8. Metal free *(human health)*	Green Plastic Pallets (5.7.)		
			Re>Pal (6.6.)		
			For Demand (8.6.)		
	b) Environmental	3.3. Low weight, space efficiency and stackability	Yellow Pallet (1.3.)	3.9. Long transportation distance from Colombia	
			CocoPallet International (2.4.)		
			Green Plastic Pallets (5.1.)		
			Re>Pal (6.1.)		
			CABKA_IPS (7.1.)		

			For Demand (8.2.)		Yellow Pallet (1.7.)
		3.5. Ecological pallets, fully circular and recycled	Yellow Pallet (1.6.)		CocoPallet International (2.9.)
			CocoPallet International (2.7.)		Biofiba (4.6.)
			Green Plastic Pallets (5.5.)		Green Plastic Pallets (5.9.)
			For Demand (8.5.)		Re>Pal (6.7.)
		3.6. Forest protection	-		
		3.7. Fire resistance *(human health)*	CocoPallet International (2.8.)		
		3.8. Metal free *(human health)*	Green Plastic Pallets (5.7.)		
			Re>Pal (6.6.)		
			For Demand (8.6.)		
	c) Social	3.4. Product superior to traditional wood pallet, with a high degree of innovation	-	-	-
		3.7. Fire resistance *(human health)*	CocoPallet International (2.8.)		
		3.8. Metal free *(human health)*	Green Plastic Pallets (5.7.)		

			Re>Pal (6.6.)		
			For Demand (8.6.)		
4. Biofiba	a) Economic	4.1. Eliminates international biosecurity risks and compliance costs	For Demand (8.1.)	4.6. Long transportation distance from Australia	Yellow Pallet (1.7.)
		4.2. Design flexibility, can meet any specification	CocoPallet International (2.2.)		CocoPallet International (2.9.)
		4.3. Long lifecycle, promotes reuse	Re>Pal (6.3.)		Bioestibas (3.9.)
			For Demand (8.4.)		Green Plastic Pallets (5.9.)
		4.4. Suitability for multiple industries and applications	Green Plastic Pallets (5.4.)		Re>Pal (6.7.)
			Re>Pal (6.4.)		
			CABKA_IPS (7.3.)		
	b) Environmental	4.3. Long lifecycle, promotes reuse	Re>Pal (6.3.)	4.6. Long transportation distance from Australia	Yellow Pallet (1.7.)
			For Demand (8.4.)		CocoPallet International (2.9.)
		4.5. Low harmful emissions during manufacturing process	Yellow Pallet (1.5.)		Bioestibas (3.9.)
			Re>Pal (6.5.)		Green Plastic Pallets (5.9.)
					Re>Pal (6.7.)
	c) Social		Green Plastic Pallets (5.4.)	-	-

		4.4. Suitability for multiple industries and applications	Re>Pal (6.4.)		
			CABKA_IPS (7.3.)		
5. Green Plastic Pallets	a) Economic	5.1. Lightweight, durable and nestable	Yellow Pallet (1.3.)	5.8. High initial investment: 75% higher than traditional wooden pallets	Re>Pal (6.8.)
			CocoPallet International (2.4.)		CABKA_IPS (7.4.)
			Bioestibas (3.3.)		For Demand (8.7.)
			Re>Pal (6.1.)		
			CABKA_IPS (7.1.)		
			For Demand (8.2.)		
		5.2. Easily cleanable	For Demand (8.3.)	5.9. Long transportation distance from USA	
		5.3. Certified for international shipment – Phytosanitary concerns: ISPM 15	CocoPallet International (2.5.)		
		5.4. Suitable for all types of industry	Biofiba (4.4.)		Yellow Pallet (1.7.)
			Re>Pal (6.4.)		CocoPallet International (2.9.)
			CABKA_IPS (7.3.)		Bioestibas (3.9.)
		5.7. Safety *(human health)*	Bioestibas (3.8.)		Biofiba (4.6.)
			Re>Pal (6.6.)		Re>Pal (6.7.)
			For Demand (8.6.)		

		5.1. Lightweight, durable and nestable	Yellow Pallet (1.3.)		
			CocoPallet International (2.4.)		
			Bioestibas (3.3.)		
			Re>Pal (6.1.)		
			CABKA_IPS (7.1.)		
			For Demand (8.2.)		
		5.2. Easily cleanable	For Demand (8.3.)		Yellow Pallet (1.7.)
	b) Environmental	5.3. Certified for international shipment – Phytosanitary concerns: ISPM 15	CocoPallet International (2.5.)	5.9. Long transportation distance from USA	CocoPallet International (2.9.)
		5.5. Fully recyclable	Yellow Pallet (1.6.)		Bioestibas (3.9.)
			CocoPallet International (2.7.)		Biofiba (4.6.)
			Bioestibas (3.5.)		Re>Pal (6.7.)
			For Demand (8.5.)		
		5.6. Pallet recovery system – Circular Economy	-		
		5.7. Safety *(human health)*	Bioestibas (3.8.)		
			Re>Pal (6.6.)		
			For Demand (8.6.)		

	c) Social	5.4. Suitable for all types of industry	Biofiba (4.4.)	-	-
			Re>Pal (6.4.)		
			CABKA_IPS (7.3.)		
		5.7. Safety *(human health)*	Bioestibas (3.8.)		
			Re>Pal (6.6.)		
			For Demand (8.6.)		
6. Re>Pal	a) Economic	6.1. Durability, space-saving and nestable design	Yellow Pallet (1.3.)	6.7. Long transportation distance from Australia	Yellow Pallet (1.7.)
			CocoPallet International (2.4.)		CocoPallet International (2.9.)
			Bioestibas (3.3.)		Bioestibas (3.9.)
			Green Plastic Pallets (5.1.)		Biofiba (4.6.)
			CABKA_IPS (7.1.)		Green Plastic Pallets (5.9.)
			For Demand (8.2.)	6.8. High initial investment: 75% higher than traditional wooden pallets	
		6.2. Less energy required to manufacture than other pallets	-		
		6.3. Closed-loop supply chain, through the use of fully recyclable pallets	Biofiba (4.3.)		
			For Demand (8.4.)		Green Plastic Pallets (5.8.)
			Biofiba (4.4.)		CABKA_IPS (7.4.)

		6.4. Selected clients across multiple industries	Green Plastic Pallets (5.4.)		For Demand (8.7.)
			CABKA_IPS (7.3.)		
		6.6. Employee and product safety *(human health)*	Bioestibas (3.8.)		
			Green Plastic Pallets (5.7.)		
			For Demand (8.6.)		
	b) Environmental	6.1. Durability, space-saving and nestable design	Yellow Pallet (1.3.)	6.7. Long transportation distance from Australia	
			CocoPallet International (2.4.)		
			Bioestibas (3.3.)		
			Green Plastic Pallets (5.1.)		
			CABKA_IPS (7.1.)		
			For Demand (8.2.)		
		6.2. Less energy required to manufacture than other pallets	-		Yellow Pallet (1.7.)
		6.3. Closed-loop supply chain, through the use of fully recyclable pallets	Biofiba (4.3.)		CocoPallet International (2.9.)
			For Demand (8.4.)		Bioestibas (3.9.)
		6.5. Low waste impact	Yellow Pallet (1.5.)		Biofiba (4.6.)

			Biofiba (4.5.)		Green Plastic Pallets (5.9.)
		6.6. Employee and product safety *(human health)*	Bioestibas (3.8.)		
			Green Plastic Pallets (5.7.)		
			For Demand (8.6.)		
	c) Social	6.4. Selected clients across multiple industries	Biofiba (4.4.)	-	-
			Green Plastic Pallets (5.4.)		
			CABKA_IPS (7.3.)		
		6.6. Employee and product safety *(human health)*	Bioestibas (3.8.)		
			Green Plastic Pallets (5.7.)		
			For Demand (8.6.)		
7. CABKA_IPS	a) Economic	7.1. Long lifespan, lightweight, stackable and space saving	Yellow Pallet (1.3.)	7.4. High initial investment: 75% higher than traditional wooden pallets	
			CocoPallet International (2.4.)		
			Bioestibas (3.3.)		Green Plastic Pallets (5.8.)
			Green Plastic Pallets (5.1.)		Re>Pal (6.8.)
			Re>Pal (6.1.)		For Demand (8.7.)
			For Demand (8.2.)		

		7.2. Business is already implemented in Portugal	-		
		7.3. Multiple applications across several industries	Biofiba (4.4.) Green Plastic Pallets (5.4.) Re>Pal (6.4.)		
	b) Environmental	7.1. Long lifespan, lightweight, stackable and space saving	Yellow Pallet (1.3.) CocoPallet International (2.4.) Bioestibas (3.3.) Green Plastic Pallets (5.1.) Re>Pal (6.1.) For Demand (8.2.)	-	-
	c) Social	7.2. Business is already implemented in Portugal	-	-	-
		7.3. Multiple applications across several industries	Biofiba (4.4.) Green Plastic Pallets (5.4.) Re>Pal (6.4.)		
8. For Demand	a) Economic	8.1. No fumigation is necessary: cheap to export	Biofiba (4.1.)	8.7. High initial investment: 75% higher than traditional wooden pallets	
			Yellow Pallet (1.3.)		

		8.2. Longer lifespan than wood pallets, lightweight	CocoPallet International (2.4.)		
			Bioestibas (3.3.)		
			Green Plastic Pallets (5.1.)		
			Re>Pal (6.1.)		Green Plastic Pallets (5.8.)
			CABKA_IPS (7.1.)		Re>Pal (6.8.)
		8.3. Easily cleanable	Green Plastic Pallets (5.2.)		CABKA_IPS (7.4.)
		8.4. Product Circularity – Closed-Loop	Biofiba (4.3.)		
			Re>Pal (6.3.)		
		8.6. Safety – no visible nails *(human health)*	Bioestibas (3.8.)		
			Green Plastic Pallets (5.7.)		
			Re>Pal (6.6.)		
	b) Environmental	8.2. Longer lifespan than wood pallets, lightweight	Yellow Pallet (1.3.)	-	-
			CocoPallet International (2.4.)		
			Bioestibas (3.3.)		
			Green Plastic Pallets (5.1.)		
			Re>Pal (6.1.)		

			CABKA_IPS (7.1.)		
		8.3. Easily cleanable	Green Plastic Pallets (5.2.)		
		8.4. Product Circularity – Closed-Loop	Biofiba (4.3.)		
			Re>Pal (6.3.)		
		8.5. Ecological and environmentally friendly	Yellow Pallet (1.6.)		
			CocoPallet International (2.7.)		
			Bioestibas (3.5.)		
			Green Plastic Pallets (5.5.)		
		8.6. Safety – no visible nails *(human health)*	Bioestibas (3.8.)		
			Green Plastic Pallets (5.7.)		
			Re>Pal (6.6.)		
	c) Social	8.6. Safety – no visible nails *(human health)*	Bioestibas (3.8.)	-	-
			Green Plastic Pallets (5.7.)		
			Re>Pal (6.6.)		

1. **Yellow Pallet** (F6S, n.d.-b)

Advantages:

1.1. Cost-effective transport pallets *(Economic)*

- The blocks made of banana fiber are used in block pallets replacing 26 to 32% of the wood volume of a block pallet;
- Price of sawn wood increases every year, contributing to a constant increase of prices of pallets on a yearly basis;
- Over 85% of the production cost of pallets consist of the required wood and 95% of all pallets in the world are wooden pallets;
- Banana fiber is a logical alternative for wood in the tropics where pallets demand is high for export of tropical fruit (e.g. bananas, pineapple, melons, among others).

1.2. Productive banana plantations *(Economic)*

- *Yellow Pallet* factories offer a price to banana growers either for their waste banana stems or for the stem parts not being used for future banana production;
- *Yellow Pallet* has specialized in growing a banana variety resistant to diseases: production capacity will be 4 - 6 times higher than a wooden forest.

1.3. Pallets are lighter than wooden pallets *(Economic and Environmental)*

1.4. Local employment *(Economic and Social)*

- Employment is created for many staff during the factory and harvesting construction: local suppliers of metals and concrete, land workers, harvesters, green house construction, electrical engineers and construction engineers;
- The factory contributes to strengthening the local economy.

1.5. Low harmful emissions during manufacturing process *(Environmental)*

- Wood for pallets is either imported from pine-producing countries located thousands of kilometers away or harvested from the parts of the mountains, destroying nature's wealth: Both methods require substantial fossil fuels to harvest and transport;
- On the other hand, banana fiber is available in abundance next to the factory locations;
- There is a benefit of 22% reduced carbon emissions compared to wooden pallets.

1.6. Biodegradable pallets *(Environmental)*

Disadvantages:

1.7. Long transportation distance from Costa Rica to Portugal *(Economic and Environmental)*

- Transport costs and environmental impact of long transportation distance will not make it attractive to deliver pallet blocks made of banana fiber from Costa Rica to Portugal.

1.8. Limited suitability *(Economic and Social)*

- Pallets are more suitable for the export of products like tropical fruits: bananas, pineapple, melons.

2. CocoPallet International

Advantages:

2.1. Low cost *(Economic)*

- Each *CocoPallet* is at least a dollar cheaper than the wooden pallets currently used.

2.2. Customizable *(Economic)*

2.3. Moisture resistant *(Economic)*

2.4. Strong capacity, nestable and lightweight *(Economic and Environmental)*

- Standard *CocoPallets* can easily handle 3000kg static load and 1500kg dynamic load;
- Space saving;
- Reduces transportation costs;
- Lowers the carbon footprint of transportation.

2.5. Certified for international shipment – Phytosanitary concerns: ISPM 15 *(Economic and Environmental)*

- Can be used for transporting food and pharmaceutical products.

2.6. Extra income for local farmers *(Economic and Social)*

- *CocoPallet* export pallets are produced close to the coco husk source.

2.7. Fully bio-based and circular *(Environmental)*

- After use, the pallets can be shredded, recycled or composted.

2.8. Insect-free, flame retardant *(Human Health: Economic, Environmental and Social)*

Disadvantages:

2.9. Facilities located at a long distance: South East Asia *(Economic and Environmental)*

2.10. One-way, single use pallets *(Economic and Environmental)*

2.11. Pallet suitability is limited, only allows the transportation of dry products: books, textiles, etc. *(Economic and Social)*

3. Bioestibas (F6S, n.d.-a)

Advantages:

3.1. Price/efficiency ratio *(Economic)*

- Low price is a capital advantage over traditional pallet competition.

3.2. Moisture resistance *(Economic)*

- Produced with a water-repellent additive that protects it from water.

3.3. Low weight, space efficiency and stackability *(Economic and Environmental)*

- The pallet weight is lower than that of a traditional pallet, which is reflected into high savings and suitability for air transportation;
- The pallet occupies a quarter of the volume of a traditional one. A truck carrying 250 traditional pallets can transport 1000 ecological pallets, clearly evidencing a highly efficient use of space;
- Reduces the contamination generated by the transport of pallets to 25%.

3.4. Product superior to traditional wood pallet, with a high degree of innovation *(Economic and Social)*

3.5. Ecological pallets, fully circular and recycled *(Environmental)*

- It allows the control and certification of final disposal of agricultural waste from crops that have hydrangea stems as the raw material being supplied;
- Biodegradable, reusable and recyclable.

3.6. Forest protection *(Environmental)*

- By taking advantage of the agricultural waste generated by floriculture (hydrangea stems), intensive forest clearing is avoided.

3.7. Fire resistance *(Human Health: Economic, Environmental and Social)*

- Ideal for industrial processes with flammable materials.

3.8. Metal free *(Human Health: Economic, Environmental and Social)*

- Pallets do not contain nails, staples or screws, which is fundamental for handling food, chemical and pharmaceutical products.

Disadvantages:

3.9. Long transportation distance from Colombia *(Economic and Environmental)*

4. Biofiba

Advantages:

4.1. Eliminates international biosecurity risks and compliance costs *(Economic)*

4.2. Design flexibility, can meet any specification *(Economic)*

4.3. Long lifecycle, promotes reuse *(Economic and Environmental)*

4.4. Suitability for multiple industries and applications *(Economic and Social)*

4.5. Low harmful emissions during manufacturing process *(Environmental)*

Disadvantages:

4.6. Long transportation distance from Australia *(Economic and Environmental)*

5. Green Plastic Pallets

Advantages:

5.1. Lightweight, durable and nestable *(Economic and Environmental)*

5.2. Easily cleanable *(Economic and Environmental)*

5.3. Certified for international shipment – Phytosanitary concerns: ISPM 15 *(Economic and Environmental)*

5.4. Suitable for all types of industry *(Economic and Social)*

5.5. Fully recyclable *(Environmental)*

5.6. Pallet recovery system – Circular Economy *(Environmental)*

5.7. Safety *(Human Health: Economic, Environmental and Social)*

Disadvantages:

5.8. High initial investment: 75% higher than traditional wooden pallets *(Economic)*

5.9. Long transportation distance from USA *(Economic and Environmental)*

6. Re>Pal

Advantages:

6.1. Durability, space-saving and nestable design *(Economic and Environmental)*

- *Re>Pal* surpasses conventional pallets in all assessed environmental indicators due to their lower replacement needs, lighter weight and lower emission during production.

6.2. Less energy required to manufacture than other pallets *(Economic and Environmental)*

6.3. Closed-loop supply chain, through the use of fully recyclable pallets *(Economic and Environmental)*

6.4. Selected clients across multiple industries *(Economic and Social)*

- Oleochemicals: Unilever OleoChemicals;
- Food: Nestle;
- Logistics/3PL: DHL.

6.5. Low waste impact *(Environmental)*

- Lowest carbon footprint of any functionally equivalent pallet;

- Lowest waste impact, since the product is from a waste feedstock and waste is reintroduced into the feedstock;
- Almost waste neutral, meaning the company uses almost as much waste during manufacture as the waste that is produced throughout its life cycle. This includes transport and end of life disposal.

6.6. Employee and product safety *(Human Health: Economic, Environmental and Social)*

- Integrity/losses avoidance.

Disadvantages:

6.7. Long transportation distance from Australia *(Economic and Environmental)*

6.8. High initial investment: 75% higher than traditional wooden pallets *(Economic)*

7. CABKA_IPS

Advantages:

7.1. Long lifespan, lightweight, stackable and space saving *(Economic and Environmental)*

7.2. Business is already implemented in Portugal *(Economic and Social)*

- The company already works with some local distributors for packaging and logistics solutions in Portugal, it could be discussed if both strategies may fit together for a potential collaboration.

7.3. Multiple applications across several industries *(Economic and Social)*

- Meat processing, pharmaceutical and health care, food, beverage, brewing, automotive, mining, furniture and pooling.

Disadvantages:

7.4. High initial investment: 75% higher than traditional wooden pallets *(Economic)*

8. For Demand

Advantages:

8.1. No fumigation is necessary: cheap to export *(Economic)*

8.2. Longer lifespan than wood pallets, lightweight *(Economic and Environmental)*

8.3. Easily cleanable *(Economic and Environmental)*

- Appropriate for industries where hygiene is a must: Pharmaceutical, food industries.

8.4. Product Circularity – Closed-Loop *(Economic and Environmental)*

- Every amount of trash generated by production can be reused on the pallets manufacture.

8.5. Ecological and environmentally friendly *(Environmental)*

8.6. Safety – no visible nails *(Human Health: Economic, Environmental and Social)*

- No visible nails therefore pallets cannot harm the merchandise or cause injuries to the employees.

Disadvantages:

8.7. High initial investment: 75% higher than traditional wooden pallets *(Economic)*

Annex C – Analyzis of quantitative data: Data collection

Companies (Suppliers)	Interview date	Interviewee	Criteria Data						
			Unit Price	Shipping Costs	Production Capacity	Weight	Static Capacity	Expected Lifetime	Lead Time
1. Yellow Pallet	18/03/2020	Hein van Opstal (Managing Director)	$12.5	N/D*	1,000,000 units/year	N/D*	2,000kg	N/D*	N/D*
2. CocoPallet International	N/D*	N/D*	N/D*	N/D*	N/D*	N/D*	N/D*	N/D*	N/D*
3. Bioestibas	15/02/2020	N/D*	$27	N/D*	504,000 units/year	18 - 25kg (Average = 21.5kg)	4,300kg	N/D*	N/D*
4. Biofiba	N/D*	N/D*	N/D*	N/D*	N/D*	N/D*	N/D*	N/D*	N/D*

5. Green Plastic Pallets	05/02/2020	Loren Krugen (CEO)	$15	$2,486.90	N/D*	7.7kg	2,268kg	10 years	N/D*
6. Re>Pal	11/02/2020	Stephen Bowhill (CEO)	$17.50	$13,225.20	N/D*	19.5kg	3,000kg	10 - 15 years (Average = 12.5 years)	N/D*
7. CABKA_IPS	05/02/2020	Naiara Loroño (Sales Director Europe South)	N/D*	N/D*	N/D*	5 – 9 kg (Average = 7.0kg)	1,600 – 3,000 kg (Average = 2,300kg)	N/D*	N/D*
8. For Demand	17/03/2020	N/D*	€13.25 = $14.93	N/D*	N/D*	7kg	2,000kg	N/D*	14 days

*N/D: Non-disclosed data. In case of *CocoPallet International* and *Biofiba*, it was not possible to conduct an interview to these companies.