TÉCNICO LISBOA

Otimização de materiais de embalagem em e-commerce

Rui Pedro Marques Tavares

Thesis to obtain the Master of Science Degree in

Industrial Engineering and Management

Supervisors: Prof. Andreia Maria Rodrigues dos Santos

Prof. Tânia Rodrigues Pereira Ramos

Examination Committee

Chairperson: Prof. Mónica Duarte Correia de Oliveira

Supervisor: Prof. Tânia Rodrigues Pereira Ramos

Member of the committee: Prof. Cátia Rafaela Ferreira Medeiros da Silva Coelho

December 2023

Declaração

Declaro que o presente documento é um trabalho original da minha autoria e que cumpre todos os requisitos do Código de Conduta e Boas Práticas da Universidade de Lisboa.

Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Acknowledgements

First of all, I would like to thank Professor Tânia Ramos for all the guidance and support throughout the completion of this dissertation. A special thanks to Professor Andreia Santos, who guided me in the environmental analysis and provided invaluable insights. Without them, this dissertation would not have been successfully completed.

I would like to express my gratitude to Rita Coelho, who assisted me with LMPT Online operations and was always available to clarify doubts and introduce me to the Porto Alto Warehouse.

To Claudia from CTT, who was willing to report the observations made online.

To Inês Caria and Sofia Alves for framing the Positive Impact policy of LM and for their ideas on how to reduce packaging consumption, especially in the use of reusable packaging.

To Martim Grange, for insights into how LCA analysis is conducted at LM and the importance of carbon neutrality in current operations.

To my friends for all the companionship and positive energy they shared, especially during the most challenging moments.

And, of course, to my parents, sister, and grandparents, who have always supported me on this long journey and provided everything necessary for my success. Without them, nothing would have been possible. It is to them that I dedicate this work.

.

To all of you, thank you very much.

Abstract

E-commerce has become a popular way for customers to make purchases. In this way, Leroy Merlin (LM), a business in the do-it-yourself (DIY) sector, has invested in the development of its online component. However, it has encountered a number of issues, including poor customer feedback regarding orders' packaging. Therefore, LM is looking to study new strategies to improve online orders' packaging costs and environmental impacts.

Thus, this work aims to develop, firstly, a standardization of packaging processes, which are currently carried out on an individual basis by operators. Given the lack of data regarding the current allocation of products to packaging, there was a need to make observations in Leroy Merlin's online warehouse, located at Porto Alto. Next, several scenarios were proposed in which different packaging materials – either single-use or reusable, and different strategies are combined.

Four scenarios are proposed, and with the implementation of a packaging standardization, analyses in materials consumption, packaging costs and environmental impacts, by performing a life cycle assessment (LCA), are carried out. The standardization reduced materials consumption at least in 76% for scenarios with manual packaging. A mixed option, including single-use and reusable packaging, is the most beneficial for environment, reducing its impacts in 83% when compared with the baseline. An automated option is the cheapest one, reducing costs in 65%. Contrary to what was analysed in most of the literature, reusable options are not the most beneficial in these dimensions. However, with higher return rates and reuse cycles, a reusable option becomes more attractive.

Keywords: Circular Economy, E-commerce, Life Cycle Assessment, Packaging Materials, Primary Packaging, Standardization

Resumo

O e-commerce é uma opção emergente na forma de efetuar compras. Assim, a Leroy Merlin (LM), uma empresa do mercado da bricolage, tem apostado na evolução da sua componente online. Porém, uma das problemáticas que enfrenta é a qualidade do acondicionamento de pequenos volumes, tendo recebido diversas críticas negativas dos seus clientes. Portanto, a LM procura novas estratégias de forma a melhorar o acondicionamento de encomendas realizadas online, considerando os seus custos e impactos ambientais.

Desta forma, foi realizada uma uniformização dos processos de acondicionamento, atualmente realizada de forma individualizada. Dada a inexistência de dados relativos à alocação atual dos produtos a embalagens, foram efetuadas observações no armazém online da LM, localizado no Porto Alto. De seguida, foram propostos diversos cenários onde é feita a conjugação de embalagens compostas por diferentes materiais e estratégias - uso único ou reutilizáveis.

Quatro cenários foram propostos, e com a implementação de uma uniformização no acondicionamento, foram realizadas análises relativas aos consumos, custos e impactos ambientais, realizando uma análise ciclo de vida, das embalagens. A uniformização reduziu o consumo de materiais em pelo menos 76% para cenários onde o acondicionamento é manual. Uma opção mista, incluindo embalagens descartáveis e reutilizáveis, tem menos impactos ambientais, reduzindo-os em 83% quando comparada com a configuração atual. A opção automatizada é a mais barata, reduzindo custos em 65%. Contrariamente ao analisado na maior parte da literatura, as opções reutilizáveis não são mais benéficas. Porém, com taxas de retorno e ciclos de reutilização superiores, esta torna-se mais atrativa.

Palavras-Chave: Análise Ciclo de Vida, Economia Circular, E-Commerce, Embalagem Primária, Materiais de Embalagem, Uniformização

List of Contents

List of Figures

List of Tables

Acronyms

3PL – Third Party Logistics

4PL – Fourth Party Logistics

APA – *Associação Portuguesa do Ambiente*

B2B – Business to Business

B2C – Business to Consumer

BOPS – Buy Online Pick Up in Store

CE – Circular Economy

DIY- Do it yourself

EU – European Union

eWOW – Electronic Word of Mouth

FE - Freshwater ecotoxicity

FEU - Freshwater eutrophication

FF - Fine particulate matter formation

FS - Fossil resource scarcity

GW – Global Warming

HNT - Human non - carcinogenic toxicity

HT - Human carcinogenic toxicity

IR – Ionizing Radiation

KPI – Key Performance Indicator

LCI- Life Cycle Inventory

LCIA- Life Cycle Impact Assessment

LDPE – Low density Polyethylene

LM – Leroy Merlin

LMPT – Leroy Merlin Portugal

LU – Land Use

ME – Marine Ecotoxicity

MEU – Marine eutrophication

MS - Mineral resource scarcity

NPS – Net Promoter Score

O&C- Order & Collect

OFH - Ozone formation, Human health

OFT - Ozone formation, Terrestrial Ecosystems

OTIF – On time in full

PA - Polyamide

PE - Polyethylene

PET - Polyethylene terephthalate

PLA – Polylactic acid

PP - Polypropylene

PVC - Polyvinylchloride

R&C- Reserve & Collect

SFP- Ship from Partner

SFS- Ship from Store

SFW- Ship from warehouse

SKU – Stock Keeping Unit

SO - Stratospheric ozone depletion

SRL – Self Run Logistics

TA – Terrestrial Acidification

TE – Terrestrial Ecotoxicity

WC – Water Consumption

ZDV – Zones of living

1. Introduction

In this chapter, an introduction to the work developed is presented. The background, and motivations behind this dissertation are described in **section 1.1**. The proposed objectives are outlined in **section 1.2**, followed by **section 1.3,** which details the methodology applied to reach these objectives. Finally, the structure of the document is presented in **section 1.4**.

1.1. Background and Motivation

The number of consumers who shop online in the European Union (EU) increased from 55% in 2012 to 75% in 2022 (Eurostat, 2023) as e-commerce has been a growing trend in the last years. This required businesses that previously sold their goods primarily through physical stores to give their customers the option of shopping online. One example of this is the DIY (Do-it-Yourself) market, where customers were used to go to the store and purchase the necessary products there.

Leroy Merlin (LM) is a DIY company and already had a website where its products were sold, but due to the COVID-19 pandemic, the website usage was increased, and LM was not logistically prepared to provide the same level of customer service when selling its products in a physical store. So, an omnichannel approach has been followed by LM, allowing customers to have an online buying experience the closest possible of buying a product in a physical store. However, there are a number of issues with selling products online, one of which is the packaging, that generally is disposable after one usage. In e-commerce, the materials used for the packaging are typically made of paper or plastic. Although these materials have undergone continuous improvement, it is becoming more difficult to reduce their costs and environmental impacts. According to APA (2023), packaging materials like plastic and paper are only recycled to a certain extent in Portugal (34% and 66%, respectively), which is a problematic when considering that these packages are currently only used once.

Regarding the online packaging, LM had received a number of negative reviews from customers. Overpackaging is a significant issue in packaging operations, and since consumers are becoming more concerned with the environmental impact of a package, it helped to explain the negative feedback received. Thus, this inefficiency also contributes to an increase in packaging materials wastes and costs because more packages are used, and more taxes related to the usage of materials are paid. In order to address this issue, the EU has already taken steps to lessen packaging waste and its effects. In accordance with the decree No. 152-D/2017's "article 23 No. 17," until 2030, at least 30% of the used packages must be reusable.

Since one of the key objectives of LM is customer satisfaction, there was a need to optimize its packaging, looking at its material composition and the most efficient way to allocate the products to the correct packages.

1.2. Objectives

The definition of objectives is used as a guideline for the methodology implementation. Considering the motivation presented, six main objectives are outlined:

- Provide a standardization for packaging of small volumes in LMPT e-commerce operations;
- Optimize packages allocations to each product and order;
- Reduce the packaging costs of the current e-commerce operations;
- Reduce the environmental impacts of the packages used, while having a comprehensive overview from raw materials extraction to its end of life;
- Decrease packaging materials consumption in order to produce the least amount of waste possible;
- Propose a reusable option which fulfils the requirements proposed by EU (by 2030, at least 30% of the packages used in e-commerce must be reusable).

1.3. Research Methodology

To fulfil the objectives proposed in the previous section, a seven step methodology was applied based on the work made by Pålsson et al. (2013) :

1. Definition of Objectives: The first step was to define the objectives to be achieved. Three main objectives are considered: Reducing packaging costs, materials consumptions, and environmental impacts. Thus, given the lack of standardization in the packaging process, it was necessary to carry out one for LMPT´s online packaging operations.

2. Data Collection: Data was obtained through: (1) LMPT documentation, (2) direct observation of the data at the Porto Alto warehouse, (3) previous studies done in the packaging context and (4) packaging suppliers' information.

3. Scenarios Definition: To implement a solution that is consistent with the objectives defined, several scenarios were proposed. The main rationale among the delineation of these scenarios was the disposability of the packages (single use or reusable).

4. Packaging Standardization: There is no packaging standardization in current operations. To address this, the observations obtained at the Porto Alto warehouse were used as basis to implement processes standardization. The goal of standardization is to streamline the packaging process while reducing costs, materials consumptions, and environmental impacts.

5. Materials Consumption: The total weight of the packages used was considered to determine the consumption of materials, taking in account the unitary weight of each package.

6. Packaging Costs: Packaging costs were calculated differently depending on whether the option is reusable or not. In the case of single-use packages, only the purchase costs and the green dot value were considered. On the other hand, for reusable packaging options, in addition to the abovementioned costs, the return rates and reuse cycles were also considered.

7. Environmental Analysis: For the environmental analysis, the ecoinvent v3 database in SimaPro was used. Beyond global warming (CO_2 emissions), other impact categories are also considered.

1.4. Document Structure

This dissertation is divided into six different chapters:

- **Chapter 1 - Introduction:** It is the current section and intends to explain the background and motivation of this dissertation, the proposed objectives and the research methodology applied to obtain them.

- **Chapter 2 - Case Study Description:** This chapter contextualizes the company, indicating its sustainability guidelines as well as how the online deliveries are functioning, and the existent problematic in small volumes packaging.

- **Chapter 3 - Literature Review:** Presents an overview of main e-commerce and business to consumer (B2C) characteristics and current practices. Thus, it contextualizes circular economy and outlines the most common packaging materials and strategies.

- **Chapter 4 - Methodology:** Describes and characterizes the methodology that was applied into this dissertation.

- **Chapter 5 - Discussion of Results:** Depicts the results obtained from the methodology and compares results regarding the proposed objectives. Additionally, sensitivity analyses are also performed in some esteemed parameters.

- **Chapter 6 - Conclusions and Future Work:** It is the final chapter and highlights the main conclusions and limitations of this dissertation along with suggestions for future work.

2. Case Study Description

In this chapter, it is made a contextualization of the problem addressed in this dissertation. **Section 2.1** describes Group ADEO, Leroy Merlin (LM) and their presence in Portugal**. Section 2.2** discusses the significance of sustainability in LM's universe, including the company's guiding principles. **Section 2.3** makes a brief reference on how Leroy Merlin Portugal (LMPT)'s supply chain works, and some objectives for the 2023-2025 period. **Section 2.4** focus on LMPT's online channel, while **section 2.5** describes the challenge in packaging small dimension products in online deliveries. Finally, **section 2.6** makes some conclusions of the chapter.

2.1. Group ADEO and Leroy Merlin

ADEO is a French Do-it-yourself (DIY) group founded in 1923 and it is currently the market leader in the European DIY market and the third largest globally. The group is one of the five owned by the Mulliez Family Association, having over 514 million customers spread across 20 countries in Europe, Asia, Africa, and South America. ADEO has a large retail network consisting of over 1 000 stores from 15 different DIY retail companies. With a workforce of 150 000 individuals, the group has a policy to prioritize people in their decisions, encouraging them to be shareholders of the company (about two-thirds of the employees are shareholders). In 2021, ADEO has reached a Gross Merchandise Value of 32.4 billion euros, out of which 2.1 billion euros are generated from the six existent online marketplaces.

Leroy Merlin is a French DIY retail company that is part of the ADEO group, operating across 14 different countries worldwide: France, Cyprus, Greece, Italy, Poland, Portugal, Romania, Russia, Spain, Ukraine, China, Brazil, South Africa, and Egypt. Established in 1923 by Adolphe Leroy and Rose Merlin, the company was initially called "Stock Américain," but it adopted the name Leroy Merlin in 1960 when the first store was opened in France. In 1981, the Mulliez family acquired the company, and currently owns approximately 88% of LM, with the remaining 12% is held by employees.

In 1989, AKI (one of ADEO's 15 retail brands) was established in Portugal. Due to a national restructuration of the ADEO Group, in 2018, AKI merged with LM, resulting in the conversion of all AKI stores to LM. Since 2003, LM has been present in Portugal, employing over 6 000 people and operating in 48 multiformat stores throughout the country, as well as online sales. Currently, LMPT national operations are performed on five regional platforms located at Algoz, Canelas, Lisboa, Mealhada, and Palmela.

In Portugal, LM is structured as shown in ***Figure 1***, being the areas approached on this dissertation highlighted in black. These areas include the Positive Impact department, where it will be focused the reduction of materials consumption and environmental impacts in products' packaging; and the Supply and Delivery department, where the focus will be on the e-commerce orders at the national level, considering home deliveries.

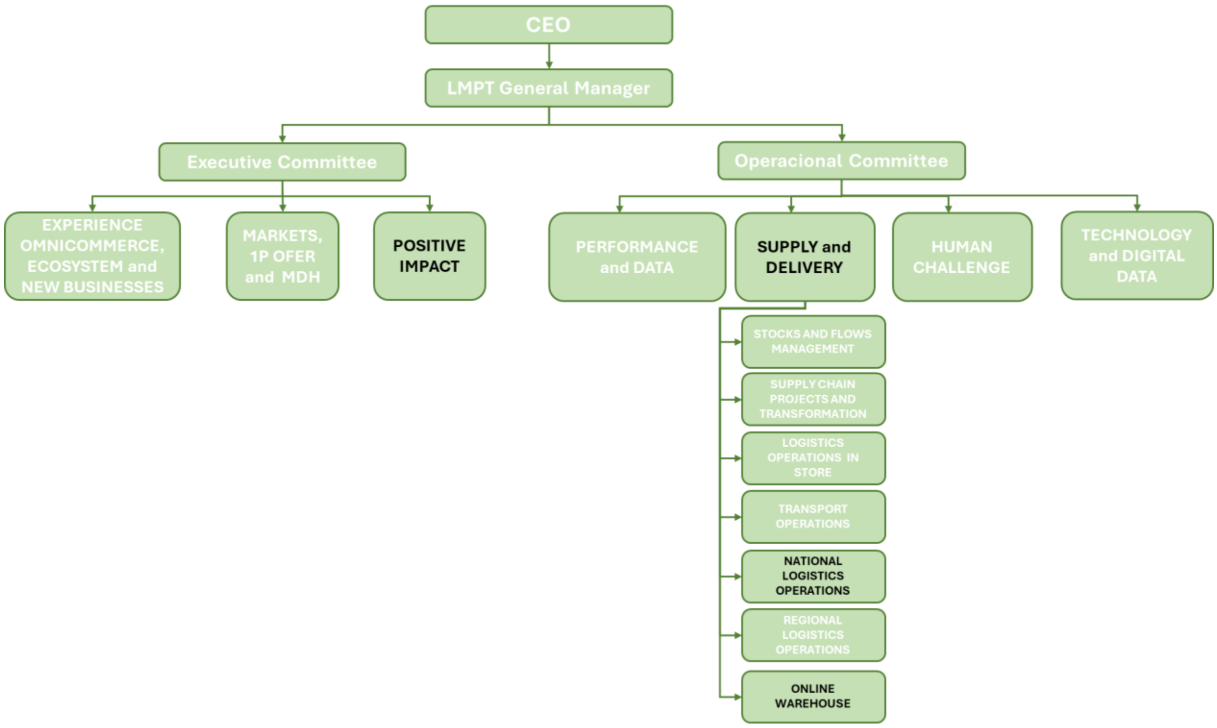


Figure 1. *Leroy Merlin Portugal Organogram.*

LMPT divides its stores in two ways: zones of living (ZDV) and format. There are eight ZDV: *Porto, Norte, Centro Norte, Centro Sul, Lisboa Oeste, Lisboa Este, Margem Sul* and *Algarve e Ilhas*. ZDV are becoming increasingly important to reinforce greater proximity and knowledge of each customer and to respond to all of their needs in a more comprehensive, immediate, and complementary manner. All ZDV are supplied by a specific regional platform ***Figure 2***.

The stores are divided into three formats according to its dimensions and number of employees that work there (**Table 1**): Small Stores/Proximity Stores (PROXI), Medium DIY stores (MSB) and Large DIY stores (GSB). Besides DIY, LM also does services such as: Equipment installation and maintenance, energy certification, order delivery and collection, online architect, budget requests, tool rental and rubble collection.

Table 1*. Stores Formats. (LMPT, 2023)*

Format	Dimensions	Number of Employees
PROXI	between 400 and 1 000 m^2	between 22 and 40
MSB	between 1 000 and 4 000 m^2	between 40 and 100
GSB	between 4 000 and 14 000 m^2	more than 100

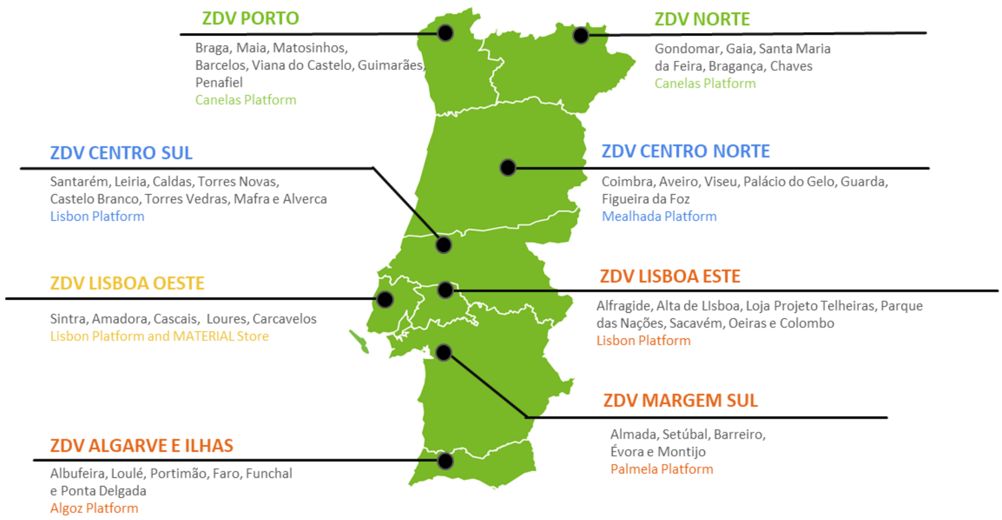


Figure 2. *LMPT's ZDV and its regional platforms. (LMPT, 2023)*

2.2. Sustainability Responsibilities

In LM, sustainability has a greater importance on how the operations are performed. To address all of these concerns, LMPT established the Positive Impact department, whose mission is to advance LMPT's development by implementing a sustainability strategy across all actions and operations at each store. This department's primary responsibilities include charting a course toward carbon neutrality and sustainable economic practices, facilitating the transition to a more environmentally and responsible business model. The Positive Impact department was formed to build a solid bridge between this department and the other ones inside LMPT (presented at ***Figure 1***). To help in the implementation of the entire Positive Impact strategy, an internal ecosystem with a set of entities and roles that enable strategy operationalization, as well as listening channels that feed strategic reflection, was required.

The sustainability policy of LM is founded on the ADEO's positive impact home (***Figure 3***) and rests on the principle of responsibility. This principle serves as the basis for the two fundamental pillars of the policy, namely human development, and habitat improvement. To ensure that the home is habitable, three essential components are required: human development, economic impact, and environmental impact.

Within each household, there are the following commitments:

Responsibility: A set of commitments that are the foundation and basis of ADEO's sustainability that must be fulfilled, consistent and credible with the corporate project.

Contribution: Focus on four major areas of contribution where LM aspire to lead:

- **Accessibility of positive solutions** (New businesses, Eco-innovations);

- **Pedagogy of Positive Habitat** (Employees promoting Positive Habitat; Labelling of product environmental performance; Pedagogy of better consumption);
- **Commitment to the local** (Indirect employment; Marketplace and short circuits; Local solidarity);
- **Building a sustainable future for everyone** (Expert employees; Habitat specialized professionals; Generations creators).

Figure 3. *ADEO's positive impact home. (LMPT Sustainability Report, 2021)*

ADEO's Portugal strategy is built on three strategic pillars of action:

- **Positive Habitat for all:** It materializes and translates Leroy Merlin's impact, given that it is through its activity that customers' lives can be improved;
- **Human Centric:** All actions are designed with the people who will be affected first and foremost in mind;
- **Circular Business:** It is only possible to be a sustainable company if the business is sustainable, and one key vector for this is the circularity of products and materials.

The products and solutions offered are central to LM's mission and purpose. They account for more than 80% of the company's environmental impact from initial conception to the end of its life. To create a positive range of products and solutions, six axes that will guide their development are identified:

1) **Made from sustainable resources:** The product is made from sustainable, traceable, and certified resources, and it has a controlled carbon footprint;
2) **Responsible production:** Its production is responsible in the sense that it respects both humans and the environment;
3) **Safe for people:** No danger to people's health;

4) **Environmentally friendly:** Ensure the safety and renewal of the planet by conserving natural and/or more sustainable resources, reducing the impact of packaging, and using eco-labels;

5) **Sustainable functions and characteristics:** The functions and/or characteristics of the products promote environmental impact reduction, such as lowering energy or water consumption;

6) **Longevity:** The product is durable and repairable.

2.3. Leroy Merlin's Supply Chain

At the moment, the supply chain of LMPT is undergoing a transformation process, with the construction of a new logistics centre in Castanheira do Ribatejo. The LMPT supply chain is supported by five boosters: Stock, Transport, Logistics, Local Logistics, and Delivery. Each booster has a goal for the 2023-2025 timeframe:

- **Stock:** Have the right stock in the right place;
- **Transport:** Value low carbon transportation;
- **Logistics:** Build resilient network;
- **Local Logistic:** Strengthen store logistic and build local logistic solution;
- **Delivery:** Speed up delivery.

Furthermore, LMPT focuses on improving certain strategic KPI's regarding efficiency, customer satisfaction, and positive impact. **Table 2** includes the indicators' values of the year 2022 and its predictions for the 2023-2025. The main objective by having these indicators is to improve the efficiency of the operations while being sustainable, especially regarding the CO_2 emissions. There are considered the following KPI's:

1) **Toxic Stock:** Percentage of stock with an average sale time higher than the expected by LMPT's supply chain;

2) **Cost:** Costs as a percentage of business unit sales.;

3) **Stock Availability:** Percentage of stock available to fulfil an order at the moment that it is placed;

4) **Net Promoter Score (NPS):** An index to evaluate customer satisfaction, based on customers response to a given question. It is explained with greater detail at **section 2.5.**

5) **Customer On Time in Full (OTIF):** Percentage of orders that met customer's expectations i.e., were delivered on time and contained exactly what was ordered.

6) **Delivery Leadtime:** The number of days (on average) between when an order is placed and when it is delivered;

7) **Carbon Footprint:** Percentage of the CO_2 emissions variation when compared with the previous year.

Table 2. *KPI's improvement prediction. (ADEO, 2023)*

Area	KPI	Year			
		2022	2023*	2024*	2025*
Efficiency	Toxic Stock	25%	20%	12%	5%
	Cost	3.1%	3.2%	3.3%	3.0%
Customer	Stock Availability	96.7%	97.4%	97.8%	98.1%
	NPS	47	48	49	50
	Customer OTIF	89%	91%	93%	95%
	Delivery Leadtime	15 days	10 days	7 days	3 days
Positive impact	Carbon Footprint	-5%	-5%	-5%	-10%

*These values are predictions.

In order to improve these indicators, one of the measures is to centralize operations by combining the national warehouse with centralized transport flows, automation, and lean policies. Currently, the warehouses related to national operations comprise an area of 62 400 m^2. With the construction of the new national logistics centre, this value will increase to 108 000 m^2.

Additionally, LMPT is revamping its online presence to enable the implementation of an omnichannel strategy. The opening of "Store 30" (dedicated to online sales) played a significant role in the application of this strategy. Store 30 is comprised of three warehouses, namely Lisbon, Porto Alto, and Meco. While functioning as a conventional physical store, Store 30 operates online through LMPT's website. Upon receiving an order from a customer, products are dispatched either directly to the customer's residence or to the nearest store based on the customer's preference during the ordering process.

The current situation of LMPT's online shopping involves multiple intermediaries, resulting in a complex and overly dependent purchasing and supply process with too many actors involved in the logistics chain, including stores, regional platforms, and distributors. To simplify the process of shipping online orders, LMPT divided it into four distinct steps: Preparation, Packaging, Expedition, and Delivery. The focus of this dissertation is to improve the packaging of LMPT's e-commerce. To better understand this problem, firstly, a closer look needs to be taken at the online deliveries functioning.

2.4. Online Deliveries

2.4.1. Overview

Online purchasing and consequently, packaging production and its use, have grown in recent years, and so has their environmental impact as a result. LM has also seen an increase in online sales, as shown ***Figure 4***, where the sales values are considered between 2020 and 2022. Given that the values for 2022 are only valid until August, it is expected that the final values will be similar to those for 2021. These sales are related to small volumes, i.e., products weighing less than 20 kg and with no dimensions exceeding 1.20 m. CTT is responsible for transporting these products, but for exceptional situations where the above criteria are not met (weight or/and large dimensions), TNB is the responsible. To be competitive, LMPT's e-commerce operations need to be adapted to meet financial and environmental goals, aligned with the Positive Impact policy.

Figure 4. *Online Sales Evolution in LMPT.*

In LMPT, e-commerce deliveries can be either home delivery or pick up in store. In ***Figure 5***, it is compared the sales value in these two options, from January to March of 2023. It is seen that the values are similar but pick up in store has slightly a higher value (55%). These different options for delivery will have different consequences regarding the way how packaging is treated. When an order is picked up at store, customers make the transportation of the products on its own vehicles, so there is no need to package products that have a primary package, since the responsibility of transportation is from the customer.

On the other hand, when it is home delivery, the shipment is up to LMPT, outsourcing these shipments to CTT and TNB, being necessary to package the products. CTT is responsible for transporting small volumes; for large volumes, TNB is used, as mentioned before.

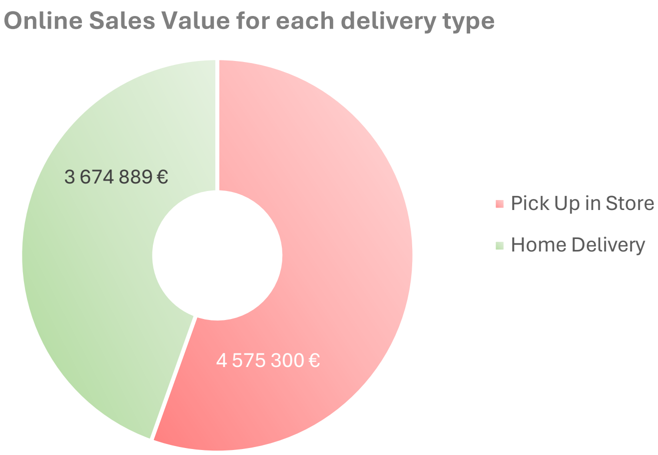


Figure 5. *Online sales values for each delivery type.*

2.4.2. Online Deliveries Omnichannel

To comprehend the operations of LMPT's online platform, it is necessary to consider two fundamental aspects: (i) the delivery location, which determines whether the order will be shipped to the customer's residence or if the customer will collect it at a designated store via the pick-up in store option; (ii) and the availability of inventory in each of the warehouses. LMPT's current e-commerce operation is established on an omnichannel policy that strives to link the virtual platform with physical stores. This policy considers four distinct components:

1) **Partners:** These pertain to the suppliers of LMPT's products;

2) **Warehouses:** These comprise the Porto Alto warehouses (warehouse 471), the Lisbon warehouses (warehouse 358) located in Vialonga, Arrogela, Azambuja, Adarse, and Póvoa de Santa Iria, and the Meco warehouse (warehouse 448) located in Spain. These three elements correspond to store 30 (the online store);

3) **Stores:** These correspond to LMPT's physical stores (GSB; MSB; PROXI);

4) **Customer:** This refers to the recipient of the order.

Naturally, these components may be interconnected based on whether the delivery is made to the customer's residence or through pick up in store. ***Figure 6*** illustrates how these flows can be integrated.

There are five flows considered in LMPT's omnichannel approach:

1) **Ship from Store (SFS):** Ship to customers' proximity store either an item on stock in store, on order from warehouse, on order from partner or on order from partner thru warehouse cross dock;

2) **Ship from Warehouse (SFW):** Ship to customers' address a warehouse item that is either on stock or it is ordered to the partner thru warehouse cross dock;

3) **Ship from Partner (SFP):** Ship to customers' address the item from the partner;

4) **Reserve & Collect (R&C):** Collect item on stock in store (stock on hand) to be picked up by a customer;

5) **Order & Collect (O&C):** Collect item on order either from the warehouse, partner thru warehouse cross dock or partner. All the items go to a physical store to be picked up by a customer.

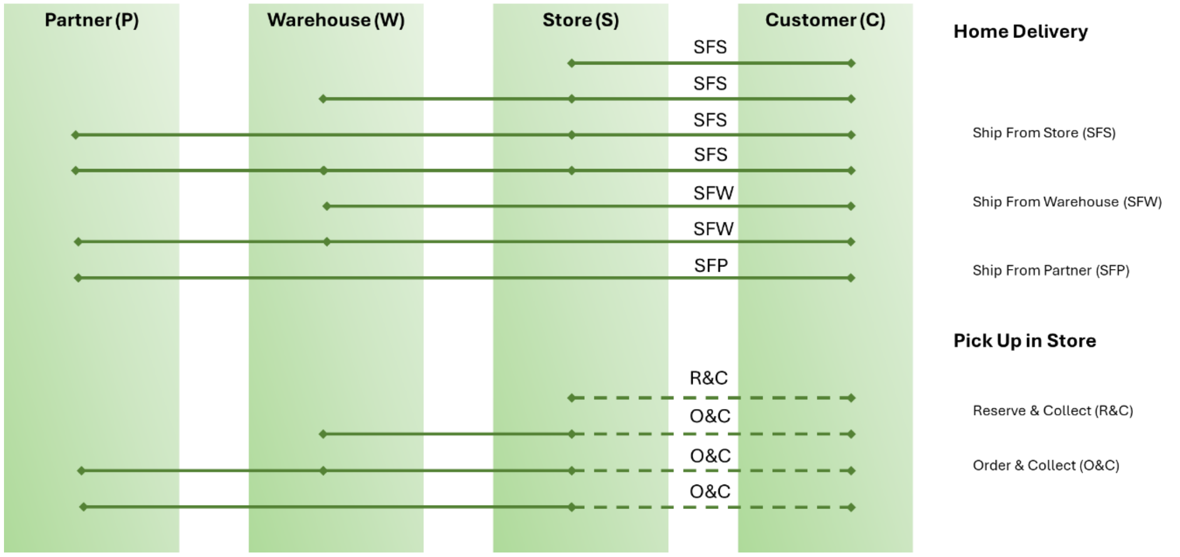


Figure 6. *LMPT's Omnichannel Flows (ADEO,2023)*

Although these flows illustrate how the elements can connect, they are not always linear and unidirectional. Considering that each warehouse only consolidates the order if it has all the references of a given order, there is sometimes a need to resort to customer's proximity stores (LMPT store that is closer to the customer address indicated when the order was placed) or directly contact suppliers. Therefore, it often happens that references are sent from various points (physical stores, suppliers, and warehouses) and consolidated on the regional platform to which the proximity store is assigned.

The way an online order is performed in LMPT is presented in ***Figure 7***. When an online order is placed, firstly the software looks for each line of the order to see if each stock keeping unit (SKU) is available in one of the store 30's warehouses (Lisbon, Porto Alto and Meco). If yes, the next step is to look at the composition of the order, i.e., how many different references does the order placed have. Either it has one or more references, it is necessary to see if the Spanish warehouse (Meco) is needed. This warehouse is only used if SKUs are not available at Portuguese warehouses, since it is more distant, implying higher costs and deliveries lead times. However, if the Spanish warehouse is used, and the order includes more than one different reference, the order is delivered two times (double delivery). Firstly, the items from Portuguese warehouses are shipped. Later the items from the Spanish warehouse are also shipped. If the Spanish warehouse is not used, all the items are delivered at once.

On the other hand, if the software retrieves that not all SKUs are available at any of the store 30's warehouses, it is looked at the proximity store of the customer. If the proximity store has all the references on stock of the placed order, it is either delivered to the customers address or it can be picked up at store. If there are references missing in the proximity store's stock, the ones that the store has are send to the regional platform responsible for the proximity store while the remaining references are directly ordered to the supplier that ships the products to the regional platform. There, the order is consolidated and delivered. All the orders are delivered by CTT or TNB, according to its dimensions and weight.

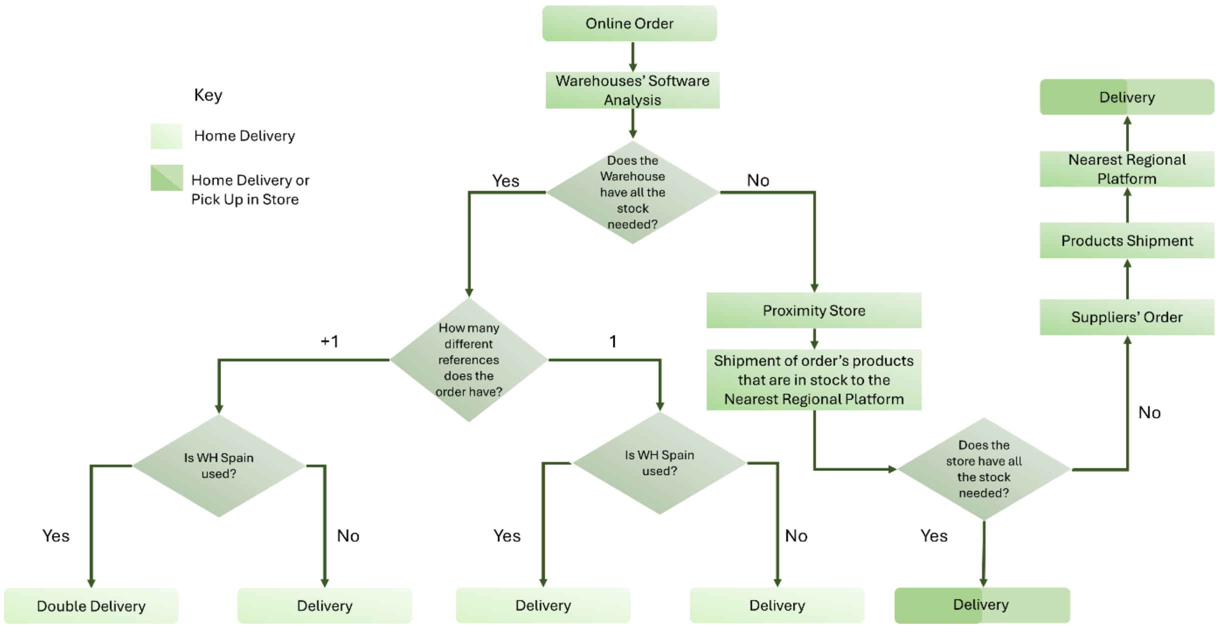


Figure 7. *LMPT's Online Omnichannel Flowchart.*

Currently, one of the primary objectives of LMPT is to centralize its online operations by including a third party logistics (3PL) specialized in Warehouse Operations, Transportation, and Marketplace in its warehouses located at Lisbon, Porto Alto and Meco. To realize this centralization, the plan is to transfer various SKUs from the Meco warehouse in Spain to the Lisbon warehouses. Later, all these operations will be performed in the new logistics centre located at Castanheira do Ribatejo. At present, the warehouse that exclusively handles online orders (situated in Porto Alto) contains roughly 12 000 SKUs of small-sized products. However, LMPT aims to augment its SKUs by adding 3 600 products that fall within the 20/80 category by the year 2025, i.e., 20% of the current references that contribute to 80% of the sales. Additionally, the inclusion of bulky and heavy SKUs, such as ceramics and wood, is also being contemplated.

2.4.3. Online Deliveries Characterization

The DIY market is characterized by having a large range of SKUs, which presents a challenge for the efficient transport and packaging of products, both in environmental and economic dimensions.

At LMPT, ***Figure 8*** shows that the average number of SKUs per online order is 1.2 SKUs when using only one warehouse (Porto Alto - 471, Lisbon - 358 or Meco). However, this average increases to 2.5 SKUs when combining references from the Lisbon warehouses with those in the Porto Alto warehouse. Considering that two warehouses are involved, the minimum number of SKUs in this case is two. Additionally, when requesting references from the Meco warehouse, only the missing SKUs are typically requested if they are not in stock at any Portuguese warehouses. Nevertheless, approximately 89% of orders can be fulfilled using only one warehouse, while the remaining 11% require SKUs from two warehouses or the warehouse in Spain. Since LM's e-commerce deals primarily with small-volume references, each order line typically consists of two units of the same SKU. Given that it is common practice to order each SKU twice, it becomes essential to consider the number of references in each order in addition to the average requirement of one SKU. The value fluctuates between 2.1 (for the Lisbon Warehouse) and 2.6 (for the Meco Warehouse) when the operation is carried out from a single warehouse. Regarding SKU sales, the warehouse 471 experienced only 1 502 SKUs sold in the year 2022, which implies that 12.5% of the SKUs present in this warehouse were sold. Moreover, it is necessary to look at the cost ratio between the average cost of shipping an order and its value, which includes expenses for transport, labour, and packaging.

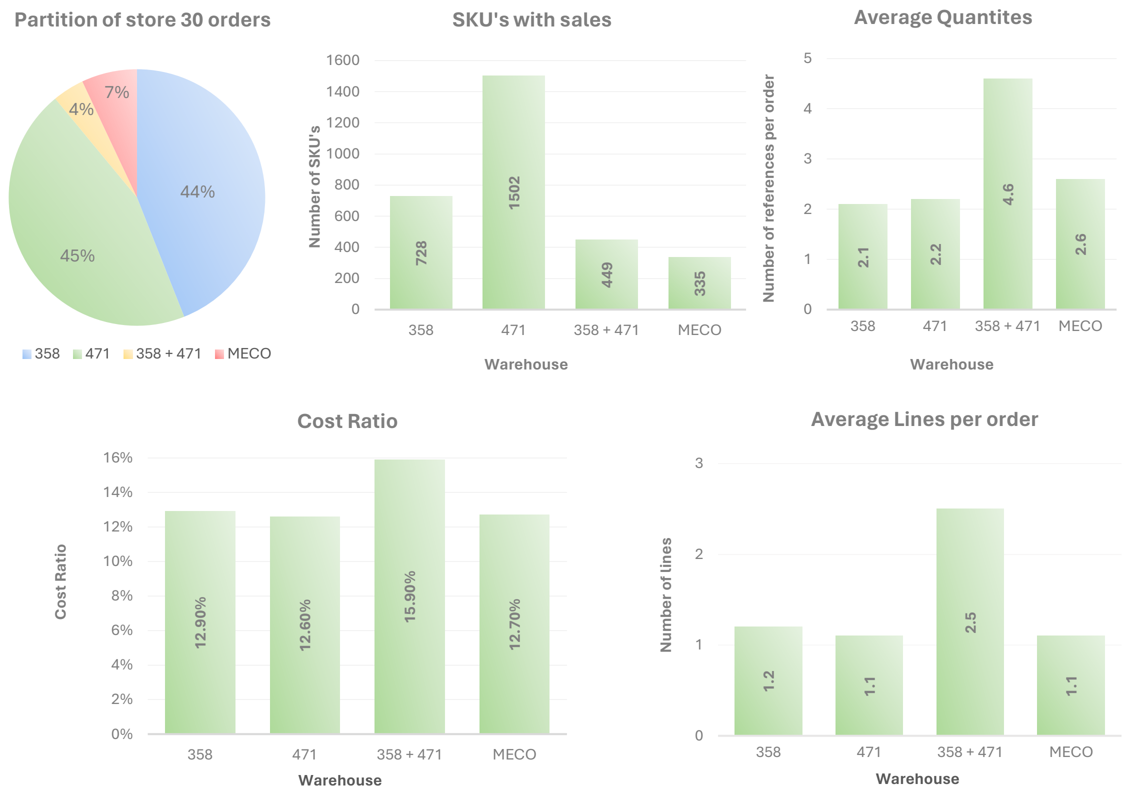


Figure 8. *Store 30 online orders information from February to April 2022.*

Figure 9 indicates the average dimensions (volume and weight) of a product ordered online. The values presented correspond to the timestamp from 20 February 2023 to 19 April 2023. It can be concluded that the majority of products have a volume lower than 5 dm^3 and a weight lower than 5 kg. Considering aforementioned factors, the process of standardizing the package may initially appear straightforward. However, it is essential to acknowledge the inherent fragility of the product, as well as the potential disparities that may arise in terms of its height, width, and length.

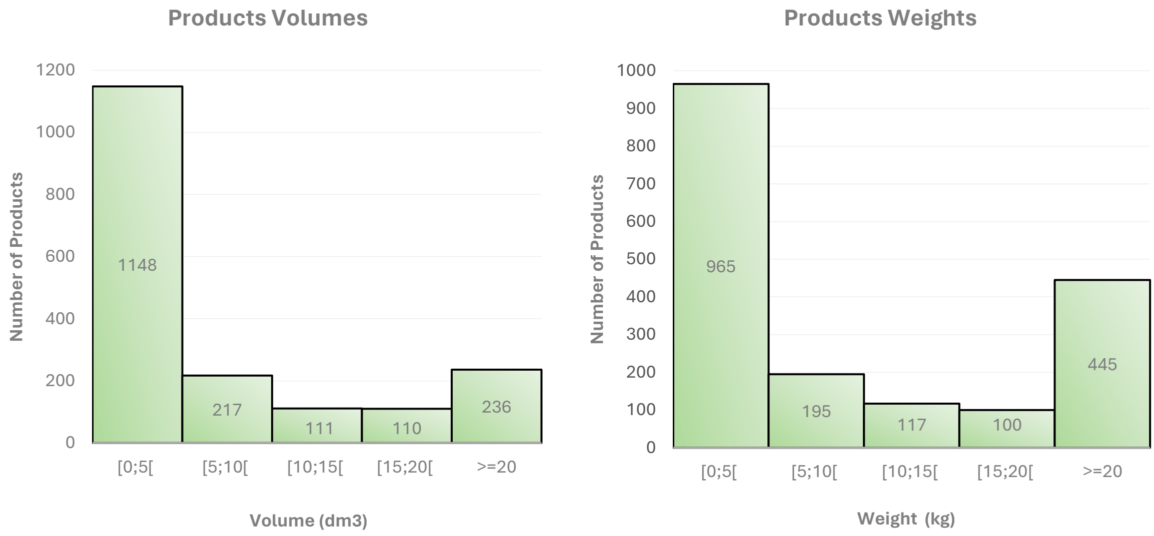


Figure 9. *Online Deliveries Dimensions for 2022.*

To streamline organization, LM has categorized its products into 13 sections, each with distinct attributes, thereby simplifying the identification of each reference in the warehouses and stores. **Table 3** provides a list of the different product families and their respective number. The lack of standardization in packaging is a matter of significant concern that requires greater attention, as it will be the focal point of the methodology to be developed to reduce costs, emissions, and waste.

Table 3. *LMPT Products Sections. (LMPT, 2023)*

Section	Description
1	Construction Materials
2	Wood
3	Comfort
4	Tools
5	Rugs
6	Ceramics
7	Sanitary
8	Kitchens
9	Garden
10	Hardware
11	Painting
12	Decoration
13	Lighting

2.5. Online Packaging

As seen in **section 2.1**, LMPT is a human centric company, so one of the company's focus its the customer satisfaction. To evaluate their satisfaction, it is used the Net promoter score (NPS) index. To compute this value, it is necessary to ask a question to be evaluated by the customer. One of the questions that LMPT asks to its costumers after the completion of an order is how satisfied they are with the packaging. Then, the customer answers the question quantitatively from 0 to 10. Subsequently, NPS divides the customers in three different groups: Promoters (which score the question with a value of 9 or 10), Neutrals (which score the question with a value of 7 or 8) and Detractors (which score the question with a value of 0 to 6). After, the NPS is obtained by subtracting the percentage of detractors to the percentage of promoters. The neutrals are not considered to obtain the index. So, NPS can range from -100 to 100 points, being values over 75 considered good. (Reichheld, 2003)

Packaging is a problem in LMPT since it has a NPS of -12. This negative score may be related with an inexistent standardization of the packaging. Each operator packages a product in a different manner, leading to a possible inefficient and inadequate packaging. Another aspect to be considered is the environmental impacts. With the lack of standardization in the process of packaging, waste tends to be augmented since some packages are used in an inefficient way leading to overpackaging of products. Furthermore, there is a need of extra interior conditioning to avoid the products to be damaged. Each type of product has different characteristics so its packaging must be adapted to each type. To better understand how to frame products, two different dimensions are considered: The number of orders of a certain section and its total value within the online sales (**Table 4**).

Table 4. *Quantities and values sold of online products in store 30 for each (2020-2022).*

Quantities sold			Value of sales		
Section	**Quantity**	**Percentage**	**Section**	**Quantity**	**Percentage**
9	766 103	21.34%	9	27 482 641 €	31.04%
1	515 568	14.36%	2	12 014 325 €	13.57%
2	427 967	11.92%	7	11 393 439 €	12.87%
10	364 486	10.15%	3	10 114 959 €	11.42%
3	310 633	8.65%	10	4 877 398 €	5.51%
6	290 509	8.09%	6	3 847 070 €	4.34%
11	190 747	5.31%	8	3 592 052 €	4.06%
12	168 969	4.71%	1	3 312 226 €	3.74%
7	165 809	4.62%	4	3 204 921 €	3.62%
4	141 735	3.95%	12	2 971 035 €	3.36%
13	136 582	3.80%	13	2 732 246 €	3.09%
8	86 412	2.41%	11	1 856 814 €	2.10%
5	24 221	0.67%	5	1 141 058 €	1.29%

Regarding the environmental dimension, the more quantities ordered, the more packages are needed. So, it is easily concluded that product families with a bigger quantity sold are more prone to produce larger waste and higher CO_2 emissions. However, the dimensions of the products also have to be considered. Normally, the majority of the products sold online in LMPT are packaged using Corrugated fibreboard boxes, which is a simple solution but sometimes not the most efficient (Pålsson et al., 2017) regarding the empty space in the package, which should be minimized.

To accommodate products, LMPT uses boxes, envelopes, stretch film, corrugated cardboard, bubble wrap and filling paper, according to each product characteristics. The packaging of a product must be divided into its interior and external packaging. Since there is no guide on how to pack a determined product, it is done in an arbitrary way by each operator. Usually, if the product already arrives within a box (primary packaging), the operator only adds stretch film around the package and puts the respective label and shipment information's. Normally, for small dimension and light products, envelopes are used. For larger SKUs, stretch film is used and then sealed with an adhesive tape. If an order is composed by two or more SKUs, generally it is used a box and the adhesive tape to seal it. Mirrors boxes are used for mirrors, since these packages have characteristics that allow to not damage the mirrors during the transportation. Stretch films are also used around the pallets to be shipped.

To consider that for larger and heavier products (over 20 kg or/and larger than 1.20m) are shipped by TNB instead of CTT. In **A.1.1** it is available the full list of packages used. Thus, LMPT also pays a tax per kg of package used (green dot value), according to the material composition of the package. The value of these taxes is available in **A.2**

So, the main objective in this dissertation will be to standardize the packaging dimensions and evaluate the best materials to use in each group of products to increase the customer satisfaction, reduce the packaging materials consumptions and environmental impacts, as well as minimizing the weight of each package to decrease costs. The standardization will be considered for the online store (store 30), where the customer should have the same experience either receiving the product at home or picking it up at store. All the materials used in the packaging should also go in line with the objectives of the Positive Impact Department while reducing at maximum the tax to be paid. The package should also obey to the "decree No.152-D/2017" where it is established at "article 23 No. 17", that until 2030, 30% of the packages used must be reusable, regardless of the material they are made of.

2.6. Chapter Conclusions

The objective of this chapter is to give a contextualization of the problem to be addressed in this dissertation. Leroy Merlin is part of the ADEO group which has a strong human and sustainable component. So, these aspects must be considered when thinking about the implementation of a new methodology which has the goal to streamline and optimize packing operations regarding packaging costs, materials consumption, and environmental impacts. LMPT e-commerce is still at a starting point hence, there are still several inefficiencies regarding the process of delivery. There are two different types of online deliveries: home delivery and pick up in store. In this dissertation, only the first will be addressed. One of the main inefficiencies in LMPT's e-commerce operations is packaging, which is made in an arbitrary way by the workers responsible to perform this operation. Thus, packaging is one of the three main drivers for the cost of an online order, adding with the labour and transportation.

Packaging is one of the main problems in LMPT online deliveries as the NPS shows. Since the company is human centric, the customers opinions assume a fundamental criterion to make decisions. Thus, there is an overall negative opinion about the packaging of the products (-12 NPS score). So, the main challenge of this dissertation will be to create a packaging methodology that uniformizes packaging operations while fulfilling the requirements of Positive Impact department. This methodology should also be aimed to minimize packaging costs, consumptions, and environmental impacts. For that, a study of packaging strategies and materials is going to be done to reduce packaging environmental impacts and materials consumption.

3. Literature Review

This chapter provides a review of previous research on the topics introduced in the **chapter 2**. **Section 3.1** frames e-commerce, and some key dimensions to be successful in this business. It includes a more in depth view on business to consumer e-commerce and the omnichannel approach. **Section 3.2** includes a brief explanation on circular economy and the importance of the Life Cycle Assessment (LCA) methodology. **Section 3.3** considers packaging, the relevance of the materials used in its end of life and the impacts of different packaging strategies. **Section 3.4** makes some conclusions of the chapter.

3.1. E-commerce

E-commerce has already been discussed extensively in the literature, but there is no general agreement on its definition. According to Zwass (1996) e-commerce “is sharing business information, maintaining business relationships, and conducting business transactions by means of telecommunications networks”. Zwass (1996) also introduces the terms business-to-business e-commerce organisations (B2B), and business-to-consumer e-commerce (B2C) when conducted between organizations and consumers. Eurostat (2019) gives a broader definition, referring to e-commerce “as the sale or purchase of goods or services, whether between businesses, households, individuals, or private organizations, through electronic transactions conducted via the internet or other computer-mediated (online communication) networks”.

Gefen (2000) adds the social aspect to e-commerce, indicating that trust and familiarity are key aspects to be taken in consideration by retailers to be successful in e-commerce. More recently, Y. Kim & Peterson (2017) confirm that, despite the evolution of e-commerce and how Internet works, trust will always be one of the main challenges to vendors. Rosario et al. (2016), adds the effect of the electronic word of mouth (eWOW) in the e-commerce market. These authors define it as an act where consumers provide information about goods and services to other consumers. Accordingly, it helps consumers to increase its trust in the buying process concluding that eWOW and sales have a positive correlation. When purchasing online, Pappas (2018) considers privacy, happiness, and customer experience. The study's findings indicate that trust alone is insufficient to make one feel good about personalized recommendations. It also suggests that privacy concerns are perceived as a secondary factor, implying that a customer can surpass it if they trust the vendor. If a vendor has experience, the consumer will be more likely to buy even if it has low trust or high privacy concerns.

E-commerce has been a growing method of sales over the last decade, with the proportion of e-shoppers in the European Union (EU) increasing from 55% in 2012 to 75% in 2022 (Eurostat, 2023) and is now the engine of the digital economy, despite existing purchase disparities between countries. To address these disparities in the EU, Bălăcescu et al. (2023) divide countries into three clusters based on Internet access, education, Internet use, e-commerce, enterprises, customer relationship management, and secure transactions. Portugal is in cluster C, which is the one with the worst performance in these categories.

The COVID-19 pandemic increased consumer interest in purchasing online, adding to an already growing trend (Y.Kim, 2020) where markets that were previously associated with the process of purchasing a product in store shifted to the online (Waliszewski & Warchlewska, 2021). The majority of DIY stores have a similar product portfolio and prices. The main distinction is the level of customer service provided (Weller et al., 2020). With the implementation of online purchasing, the concept of multichannel emerges, separating physical stores from online stores, giving rise to "bricks and clicks" stores. However, as mobile technologies advanced, it became possible to seek integration between offline and online channels, giving rise to the omnichannel concept. Omnichannel strategies aim to provide customers with the same experience across all channels, placing a greater emphasis on the interaction with the brand rather than the channel used (Piotrowicz & Cuthbertson, 2014).

3.1.1. B2C e-commerce

Buyers' productivity increased as a result of the adoption of B2C in an e-commerce context, allowing them to have fast, price transparent transactions (Huseynov & Özkan Yıldırım, 2019), search for product information, and generally improve their decisions. However, vendors do not always meet the information needs of online consumers, resulting in a lack of transparency. Product features, product quality, e-vendor warranty policy, and ordering method are all regarded as important contributors to transparency (Zhou et al., 2018).

In comparison to the offline market, B2C e-commerce presents unique challenges due to the increased complexity of logistics activities. The efficient management of logistics plays a crucial role in the success of B2C e-commerce, as it enables cost reduction by establishing effective connections between warehouses and customers. Collaborative efforts among warehouses in fulfilling multiple-item orders can expedite item delivery (Mangiaracina et al., 2019). The adoption of logistics resource sharing has become a prominent trend in B2C e-commerce. As stated by Lieb et al. (1993), third-party logistics (3PL) involves outsourcing logistics functions that were traditionally performed internally within an organization. Van Laarhoven et al. (2000) underscore the provision of management support as a defining characteristic of 3PL, wherein logistics service providers execute transportation and warehousing activities on behalf of the shipper. Bask (2001) presents a more comprehensive definition of 3PL, describing it as a relationship between supply chain interfaces and third-party logistics providers. This relationship entails the provision of logistics services, ranging from basic to customized, within a short or long-term framework, with a focus on achieving effectiveness and efficiency.

He et al. (2019) conducted a comparative analysis of resource sharing between two companies: one employing self-run logistics (SRL) and the other utilizing third-party logistics (3PL). Their findings indicate that logistics sharing consistently increases the optimal pricing for the company employing a 3PL strategy. Additionally, logistics sharing often leads to customer migration from the SRL provider to the 3PL company, while increasing the profitability of the 3PL company. However, the benefits of logistics sharing for the SRL company may be limited unless there is a significant disparity between the SRL and 3PL companies. In summary, logistics sharing consistently favours the 3PL company. Addressing the challenges faced in supply chain management, Wang et al. (2021) highlight logistics operations and suboptimal resource utilization as significant concerns. To tackle these issues, the concept of fourth-party logistics (4PL) was introduced. Accordingly, 4PL aims to reduce costs, enhance efficiency, and provide superior quality and flexibility in logistics services.

3.1.2. Omnichannel

The retail industry and customers have undergone a transition from a multichannel to an omnichannel approach, driven by the rapid development of digital channels such as mobile and social media (Verhoef et al., 2015). This shift is a response to customers' increasing familiarity with diverse retail channels and their more sophisticated purchasing behaviours (Shi, 2017), as they seek a seamless purchasing experience across online and offline (Beck & Rygl, 2015; Bell et al., 2018; Verhoef et al., 2015).

Channel, as defined by Neslin et al. (2006), refers to a touchpoint or medium through which the firm and the customer interact. Beck & Rygl (2015) provide a categorization of different multiple channel approaches, distinguishing between multichannel, cross-channel, and omnichannel **(*Table 5*)** based on two dimensions: (1) whether channel interaction is customer-triggered or controlled by the retailer, and (2) the number and types of channels considered. The emergence of multichannel strategies can be attributed to the growth of the internet (S. C. e. Silva et al., 2018). Neslin et al. (2006) define multichannel customer management as “the design, deployment, coordination, and evaluation of channels to enhance customer value through effective customer acquisition, retention, and development”. In multichannel retailing, operations are often conducted independently in parallel for direct-to-customer shipments and store supply, resulting in a cannibalization effect rather than the creation of synergies between online and offline channels (Hübner et al., 2016).

Empirical analysis by Y. Kim & Peterson (2017) suggests that customers' risk aversion and service orientation influence the preference for online channels over offline channels, leading to channel cannibalization by the online channel. Huang et al. (2016) demonstrate that the introduction of a new mobile channel alongside an existing web channel may cause slight cannibalization of the latter. However, the overall purchase value increase, indicating that the positive synergies outweigh the negative cannibalization effect. Herhausen et al. (2015) recommend the integration of online and offline channels, noting that such integration enhances perceived service quality and, consequently, improves internet outcomes. This integration does not have a detrimental impact on physical stores but rather facilitates the creation of synergies between the channels instead of channel cannibalization.

***Table 5**. Taxonomy of Multiple Channel Retailing. (Beck & Rygl, 2015)*

Dimension 1	Dimension 2	Concept	Category
No interaction can be triggered by customer.	More than one channel or all channels widespread at that time	Multi-Channel Retailing	I
No integration is controlled by retailer.			II
Partial interaction can be triggered by customer.			III
Partial integration is controlled by retailer.		Cross-Channel Retailing	IV
Full interaction can be triggered by customer.	More than one channel but not all channels widespread at that time		V
Full integration is controlled by retailer.			VI
Full interaction can be triggered by customer.	All channels widespread at that time	Omni-Channel Retailing	VII
Full integration is controlled by retailer.			VIII

This need of channel integration provoked an increased focus in omnichannel retailing**.** Verhoef et al. (2015) define omnichannel management as "the synergetic management of the numerous available channels and customer touchpoints, in such a way that the customer experience across channels and the performance over channels is optimised". Cao & Li (2015) identify that the integration of online and offline channels allows to: (1) improve trust, (2) increase customer loyalty, (3) higher consumer conversion rates, (4) greater opportunities to cross sell, and (5) the loss of special channel features. S.C. e. Silva et al. (2018) study the factors that affect consumer acceptance of using technologies that allow to adopt an omnichannel strategy. It is concluded that perceived risks and costs associated with the adoption of an omnichannel do not have significant influence on the intention to adopt, so companies may achieve competitive advantage by adopting an omnichannel approach.

In the omnichannel approach, showrooming is gaining importance, where customers look the products in store before buying them online with a cheaper price. Showrooming has become a threat to brick and mortar stores (Shi, 2017) and according to Bell et al. (2018) showrooming helps to: (1) increase the overall demand;(2) generate attract customers that have a higher cost-to-serve; (3) improve overall operational and (4) amplify demand and operational benefits.

Recently, retailers have been adopting a BOPS (buy online and pick up in store) strategy. Gao & Su (2017) studied the impact of BOPS in store operations and found that: (1) products that sell well in store are not suited to be picked up in store; (2) BOPS allows retailers to reach new customers but for existing customers the shift from online to offline may decrease profit margins.

3.2. Circular Economy

The circular economy (CE) is a significant focus for the EU as it aims to maximize the recycling and re-use of waste (Roithner & Rechberger, 2020). Geissdoerfer et al. (2017) define CE "as a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling". Mura et al. (2020) identify three key features of CE: (1) the capability of auto-regeneration through eco-innovations, preserving raw materials; (2) the maximization of product life cycles; and (3) the transition to new consumer habits. However, according to Sijtsema et al. (2020), this transition is still not attractive enough to consumers. These features align with the field of eco-design design (Mendoza et al., 2017), but den Hollander et al. (2017) distinguish between the concepts of CE and eco-design. Accordingly, in CE waste is considered non-existent, following a cradle-to-cradle life cycle, whereas in eco-design, waste is recognized as one of the guiding principles, as defined by the Waste Framework Directive (EU, 2018) , which defines waste as "any substance or object which the holder discards or intends or is required to discard".

The inclusion of product recycling is necessary to foster CE (Bakker et al., 2014), as it is considered a cornerstone of European waste legislation (Roithner & Rechberger, 2020). However, the quality of recycled materials plays a significant role in enabling effective recycling. When compared to products using virgin materials, the quality of the latter is generally better (Eriksen et al., 2019), as the mechanical properties of materials processed multiple times deteriorate with the number of usages (Mrówczyński et al., 2022). In contrast to traditional linear economies, CE aims to retain value and minimize waste in products (Grdic et al., 2020), providing financial, social, and environmental benefits (Lewandowski, 2016). One of the most widely used frameworks for implementing CE is the ReSOLVE framework developed by the Ellen MacArthur Foundation (2015) which encompasses six business actions: (1) Regenerate, involving a shift to renewable energy and materials; (2) Share, by keeping the speed of product loops low and maximizing their usage; (3) Optimize, enhancing the performance and efficiency of products; (4) Loop, keeping components and materials in closed loops and prioritizing inner loops; (5) Virtualize, delivering utility virtually; and (6) Exchange, replacing old materials with advanced non-renewable materials. The EU (2019) presents several key performance indicators (KPIs) for analysing the performance of CE, with the Global warming potential (GWP), also known as the carbon footprint, being one of the main indicators considered in this context. Thus, the main indicator considered in this dissertation is the Global warming potential. The measure unit used is t CO_2 eq., and it is usually obtained by using the Life Cycle Assessment (LCA) methodology.

Indeed, LCA is widely recognized as a valuable methodology for evaluating the environmental impacts associated with the entire life cycle of a product (Kan & Miller, 2022). It can also serve as a decision-making tool in various contexts (Kaab et al., 2019). The LCA methodology is covered by International Organization for Standardization (ISO) standards 14040:2006 and 14044:2006, which provide guidelines for conducting an LCA and address the environmental aspects and potential impacts using a life-cycle approach (ISO, 2006).The LCA typically consists of four main steps: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA), and (4) interpretation. However, it is important to acknowledge that there are some drawbacks associated with using the LCA methodology. Holdway et al. (2010) highlights a few limitations. Firstly, LCA may not be suitable for accurate assessments during the early stages of product development when detailed information regarding material use, energy consumption, and environmental impacts is lacking. It is typically more feasible to conduct an LCA when a product is well-defined, and information is readily available. Secondly, conducting an LCA can be resource-intensive in terms of time and cost. Collecting data, performing calculations, and interpreting the results require significant effort and expertise. This can pose challenges for organizations with limited resources or tight timelines.

3.3. Packaging

3.3.1. Packaging Materials

Packaging materials have undergone a continuous evolution until the 1990s. However, in recent years, it has become increasingly challenging to improve their cost efficiency and minimize their environmental impact. Certain packaging products still rely on non-renewable materials, which poses limitations on their growth potential (Escursell et al., 2021). Material selection plays a crucial role in addressing these challenges and improving the sustainability of packaging (Peças et al., 2013). Among the various packaging materials, paperboard stands out as the most widely used material globally, being followed by flexible packaging materials (such as envelopes and films) and rigid plastics, ranked as the second and third most consumed packaging materials respectively (Statista, 2022).

Paper and Carboard

Paper and cardboard are cellulose based materials, made out of lower grade wood fiber which usually includes recycled paper, and cardboard waste (Sevigné-Itoiz et al., 2015). Cellulose is safe for the environment being considered a renewable and sustainable raw material. Its mechanical properties, reinforcing capabilities, abundance, low density, and biodegradability make cellulose a versatile source for several packaging materials, especially in food packaging (Suhas et al., 2016; Vilarinho et al., 2018). These has led to a shift from plastic to paperboard packaging.

Corrugated cardboard is a layered structure that derives its strength from the selection and combination of individual flutes or holes within the material (Leminen et al., 2019). The strength of corrugated cardboard is influenced by two characteristics in the plane directions: the machine direction and the cross direction. The machine direction refers to the direction that is perpendicular to the main axis of the corrugated cardboard and parallel to the alignment of the paperboard fibres. The cross direction, on the other hand, runs parallel to the fluting of the cardboard (Garbowski et al., 2021). These two directions play a significant role in determining the strength and performance of the cardboard. In terms of hole design in corrugated cardboard, Han & Park (2007) conducted a study and concluded that the compression strength of the box could be preserved by using ventilation holes with specific characteristics. According to their findings, if the length of the major axis of the ventilation hole is less than 1/4 of the depth of the box and the ratio of the minor axis to the major axis falls within the range of 1/3,5 to ½,5, with even-numbered holes located symmetrically, the decrease in compression strength can be minimized. While cardboard is an ideal material for shaping packaging (Mrówczyński et al., 2022), there are factors that can reduce its load-bearing capacity (Frank, 2014).

The impact of paper recycling on greenhouse gas (GHG) emissions, specifically in terms of carbon dioxide equivalent (CO_2 eq.), has been examined in the study conducted by Merrild et al. (2009). Their findings demonstrate that substantial GHG savings can be achieved by expanding the system range in paper recycling. Consequently, it is inferred that the contributions of upstream and operational GHG emissions are negligible compared to the indirect downstream emissions. These contributions amount to approximately 1 to 29 CO_2 eq. per tonne of paper waste and 490 to 1640 CO_2 eq. per tonne of paper waste, respectively. Merrild et al. (2009) also highlight the presence of material recovery facilities that enable the recycling of paper either separately or as a mixed material. The two primary methods employed for paper reprocessing are mechanical re-pulping and chemical-mechanical repulping. The recycling process for paper and cardboard closely resembles that of virgin fibres, as discussed by Geueke et al. (2018). In a comparative analysis conducted by Cottafava et al. (2021) on single-use cups made of plastic and cardboard, it is concluded through a LCA that cardboard cups exhibit lower CO_2 emissions when compared to plastic alternatives.

Flexible Packaging and Plastics

The plastic industry relies on various polymers, including polyvinylchloride (PVC), polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE), and polyamide (PA), due to their favourable mechanical and physical characteristics (Luzi et al., 2019). Flexible packaging, on the other hand, is composed of blends or layers of different thin materials such as low-density polyethylene (LDPE), PE, or PP (Bening et al., 2021; Garofalo et al., 2018).

The life cycle of plastics comprises three phases: production, use, and end of life, as illustrated in ***Figure 10,*** where "*F*" corresponds to a given material flow. During production, various chemical substances are incorporated into the plastic to enhance its properties and overall life cycle (Hahladakis et al., 2018). The properties of polymers are determined by the structure of their constituent monomers, and through heat processing, the polymeric material is shaped and transformed into plastic (Elias & Mülhaupt, 2015). While conventional plastics are derived from fossil resources, bioplastics utilize renewable resources (biomass) that undergo chemical polymerization mechanisms. The packaging sector constitutes the largest market for plastics, primarily driven by the transition from reusable to single-use packages. Consequently, plastic waste has been steadily increasing over the past five decades (Rosenboom et al., 2022). The permanent disposal of plastic waste can only be achieved through destructive thermal treatments such as combustion or pyrolysis, which extract fuel from plastic waste. However, the predominant method of thermal destruction has been incineration, with or without energy recovery. Despite these efforts, a significant majority of plastics (79%) still end up in landfills or the environment (Geyer et al., 2017). In an ideal circular economy scenario, plastics would be derived from recycled or renewable sources. Two primary plastic recycling techniques are commonly employed: (1) mechanical recycling, which employs mechanical forces and heat to shape plastics, with the final product quality being highly dependent on the initial plastic quality (Rosenboom et al., 2022); and (2) chemical recycling, which involves depolymerizing the plastic to recover the monomers. These monomers, once separated, can be used to create new plastics without any loss in properties, thereby enabling a circular economy approach to plastic materials (Coates & Getzler, 2020).

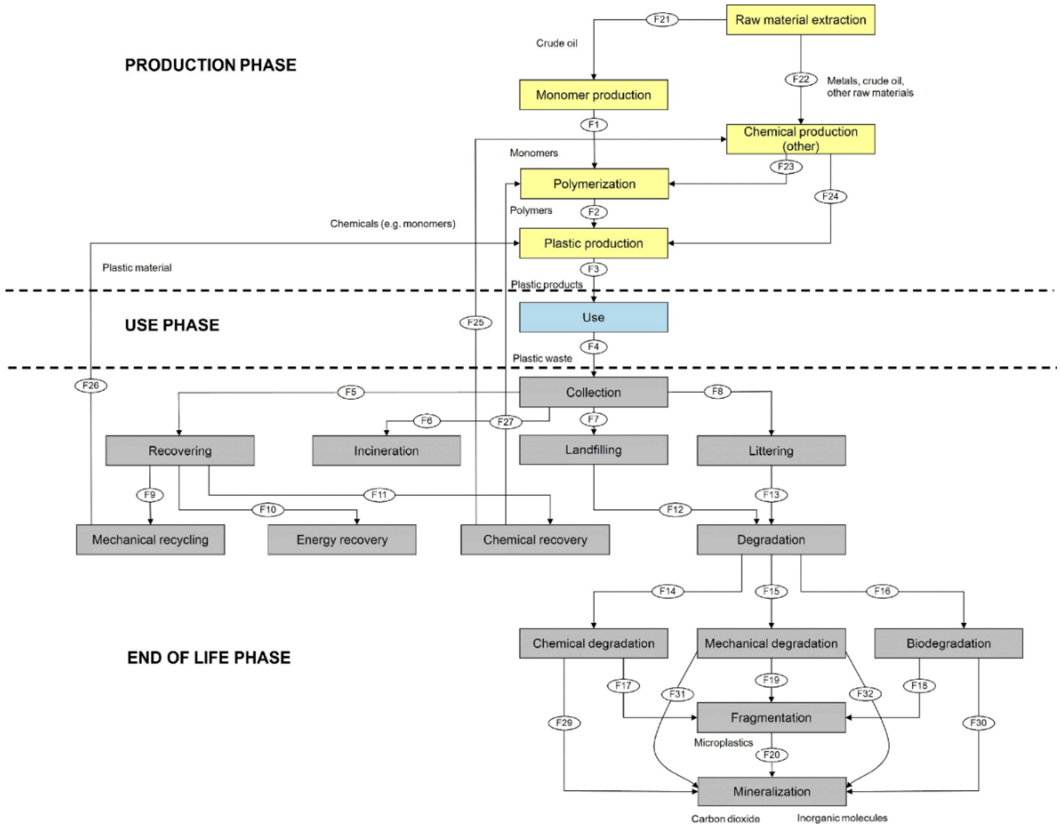


Figure 10. *Plastics Life Cycle. (Hahladakis et al., 2018)*

Two additional approaches used for plastic recycling are Re-Extrusion (or closed-loop process) and incineration. Re-Extrusion involves the injection moulding of clean or semi-clean plastic parts into recycled products, allowing the final product to serve the same purpose as the original (Sadat-Shojai & Bakhshandeh, 2011; Singh et al., 2017). On the other hand, incineration refers to the thermal treatment of plastic waste. Flexible plastic films have gained popularity due to their versatility, lightweight nature, resistance, and printability (Horodytska et al., 2018). These films can be classified into two groups: monolayer films and multilayer films. Monolayer films consist of a single thermoplastic polymer sheet made from PE, PP, or PET, typically used as secondary or tertiary packaging (e.g., stretch film). Multilayer films, on the other hand, comprise multiple layers of polymeric (thermoplastics) and non-polymeric materials, primarily used for primary packaging purposes (Wagner, 2016).

When it comes to the LCA studies on waste management of flexible plastic films, there is a scarcity compared to rigid plastics (Horodytska et al., 2018). In a study by Siracusa et al. (2011), two envelopes made of LDPE and PA films with different thicknesses (70 and 90 μm) were compared. It was found that the difference in thickness led to a 23% reduction in damage loss, and the production of plastic from raw materials had the highest environmental impact. Therefore, the use of recycled granules in film production was recommended. Tamburini et al. (2021) conducted an LCA analysis comparing PET, bioplastic, and refillable aluminium water bottles. They concluded that refillable bottles were advantageous due to their reusability. Among the plastic bottles, PET bottles had a lower environmental impact compared to bioplastic bottles, which only showed an advantage during the agricultural phase of the bottle's life cycle. Ahamed et al. (2021) performed an LCA comparing different grocery bags in Singapore. Reusable bags and HDPE bags were found to be better options than paper or cloth bags. The use of the latter would increase the environmental footprint, resulting in negative effects such as global warming and eco-toxicity potentials. In a study by Cottafava et al. (2021) comparing reusable plastic cups using LCA analysis, PP was found to have the lowest CO_2 emissions, followed by PET and Polylactic acid (PLA), when considering the same number of usage cycles. ***Table 6*** provides a comparison of the discussed materials, considering their packaging properties, recyclability, and reusability.

3.3.2. Packaging Strategies

On 30th November 2020, EU proposed a new directive on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC. With this, the main objective is to reduce waste and improve packaging circularity. Three options are given: “Option 1 sets out measures to increase standardisation and establishes clearer essential requirements that tend to be pre-requisites for measures in other groups; Option 2 sets mandatory targets for waste reduction, re-use for certain sectors and minimum recycled content in plastic packaging, requirements to ensure full recyclability by 2030 and harmonised product rules; Option 3 sets higher mandatory targets than Option 2 and additional product requirements” (EU, 2022).

The discourse surrounding packaging and its environmental ramifications has predominantly centred on consumer packaging, prompting governmental authorities to implement regulatory measures such as eco-taxes, including initiatives such as "*Valor Ponto Verde*," and deposit-return systems (Verghese & Lewis, 2007; Sociedade Ponto Verde,2023). Packaging encompasses three interconnected hierarchical levels: (1) Primary package denotes the immediate interface between the packaging and the product, primarily handled by end-users. Its principal functions include safeguarding the product and serving as a promotional tool. Multiple primary packages can subsequently be consolidated into a (2) secondary package (typically in the form of boxes), which facilitates handling within retail settings and represents the package exhibited in stores. Furthermore, a (3) tertiary package can be employed to amalgamate numerous primary or secondary packages, thereby forming larger loads that enable enhanced transportation efficiency (Escursell et al., 2021; Lindh et al., 2016; Meherishi et al., 2019; Pålsson et al., 2013). Evidently, consumers demonstrate a genuine concern regarding the environmental implications associated with packaging choices, as illustrated by Herbes et al. (2018) where consumers have tendency to favour biodegradable options over non-biodegradable alternatives.

Table 6. *Packaging Materials Comparison. (Considering only the most used in packaging)*

Material	Packaging Properties (Selke & Culter, 2016) (Fibrebox,2021)	Recyclable	Reusable	Authors
PET	• Reasonably good oxygen and carbon dioxide barrier, • Excellent odor barrier properties, • Generally used for packaging food.	Yes.	Yes.	(Luzi et al., 2019);(Hahladakis et al., 2018);(Elias & Mülhaupt, 2015);(Coates & Getzler, 2020);(Geyer et al., 2017);(Singh et al., 2017):(Sadat-Shojai & Bakhshandeh, 2011);(Horodytska et al., 2018);(Tamburini et al., 2021);(Cottafava et al.,2021)
PP	• Used for packaging film and containers, • High stiffness, • Excellent moisture barrier, • Medium transparency	Yes.	Yes.	(Luzi et al., 2019);(Bening et al., 2021);(Cottafava et al., 2021):(Garofalo et al., 2018);(Hahladakis et al., 2018);(Elias & Mülhaupt, 2015);(Coates & Getzler, 2020);(Geyer et al., 2017);(Singh et al., 2017);(Sadat-Shojai & Bakhshandeh, 2011);(Horodytska et al., 2018);(Cottafava et al.,2021)
HDPE	• Stronger, stiffer, and less permeable when compared with LDPE, • Nontransparency • Good moisture barrier properties, • Poor oxygen and organic compound barrier characteristics.	Yes.	Yes.	(Luzi et al., 2019);(Bening et al., 2021);(Garofalo et al., 2018);(Coates & Getzler, 2020);(Geyer et al., 2017);(Sadat-Shojai & Bakhshandeh, 2011);(Horodytska et al., 2018);(Ahamed et al., 2021)
LDPE	• Excellent flexibility, • Good impact strength, • Fair machinability, • Good oil resistance • Fair chemical resistance, • Good heat sealing characteristics, • Low cost. • Better transparency than HDPE	Yes.	Yes.	(Bening et al., 2021);(Garofalo et al., 2018);(Hahladakis et al., 2018);(Elias & Mülhaupt, 2015);(Singh et al., 2017); (Sadat-Shojai & Bakhshandeh, 2011);(Siracusa et al., 2011*)*
Cardboard	• Lightweight, • Low Costs, • Easily customisable • Structural rigidity with cushioning qualities to protect heavy or fragile contents from damage.	Yes.	Generally, No. According to (Fibre Box, 2021), fibres can be recovered allowing to reuse it from 7 to 10 times.	(Peças et al., 2013);(Sevigné-Itoiz et al., 2015);(Suhas et al., 2016) ;(Vilarinho et al., 2018);(Leminen et al., 2019);(Garbowski et al., 2021);(Han & Park, 2007);(Mrówczyński et al., 2022) ; (Merrild et al., 2009);(Cottafava et al.,2021)

One popular and widely adopted approach in the field of packaging is the 4Rs strategy, initially proposed by Klooster (2002). The 4Rs stand for recycle, reuse, renew, and rethink, encompassing key principles for sustainable packaging practices. A significant proportion of research and studies conducted on packaging strategies align with one or more of these categories. Escursell et al. (2021) provide a comprehensive overview of the prevailing challenges within the current packaging paradigm, highlighting three primary issues: overpackaging, utilization of non-renewable materials, and distribution of packages. To address these challenges, several solutions have been proposed. Firstly, the promotion of circular packaging practices aims to minimize waste and maximize the lifecycle of packaging materials. Additionally, the utilization of additive manufacturing and 3D printing technologies offers the potential to create customized packaging solutions that optimize material usage, resulting in cleaner manufacturing processes and reduced carbon dioxide (CO_2) emissions. In the context of e-commerce, Lu et al. (2020) argue that overpackaging often occurs as a means to enhance product protection and mitigate the risk of receiving negative consumer reviews. However, this practice contributes to additional waste generation. The study presents a compilation of 13 diverse solutions for addressing overpackaging, with the optimization of packaging strategies being the most widely accepted among consumers.

Coelho et al. (2020) propose reusable packaging as a potential solution for reducing environmental impacts, with a specific focus on minimizing the packaging material per unit of packed volume. Shifting from material recycling to product cycle would offer greater benefits as it retains the functionality of the materials. This approach presents an opportunity to reduce product usage and emissions. While cardboard and wood packaging are typically considered disposable options, plastic containers have the potential to be infinitely reusable and recyclable. However, Accorsi et al. (2020) highlight that implementing reusable packaging involves more complex operations compared to disposable packaging. Reusable packaging systems have been shown to be more efficient in reducing the volume of packaging materials, energy usage, and production emissions. The Ellen MacArthur Foundation (2019) suggests that up to 20% of plastic packaging could be replaced by reusable systems. The European Parliament aims to increase the share of reuse to 10% by 2030 (European Parliament, 2023)**.** However, it is important to acknowledge that transitioning to reusable packaging may not be feasible or sustainable for all supply chains (Coelho et al., 2020) due to factors such as unrecyclable materials or complex logistics. Gardas et al. (2019) identify three critical success factors for implementing a reusable packaging system: top management commitment, lean support, and optimized inventory management. To facilitate the efficient return of empty containers, Glock & Kim (2014) propose the use of RFID technology, which not only encourages timely returns but also provides economic benefits. Cobb (2016) also suggests that RFID can improve inventory control and enable better tracking of reusable packages.

Reverse logistics, as demonstrated by Silva et al. (2013), plays a vital role in contributing to technical, economic, and environmental aspects of business sustainability. Although reverse logistics incurs higher costs and complexity compared to forward logistics, it has been shown to have lower environmental impacts. In the same work it is proposed a returnable packaging model to replace disposable packaging and use LCA techniques to demonstrate the lower environmental impacts of returnable packaging. In the context of cosmetic plastic packaging, Gatt & Refalo (2022) conclude that the positive effects of reusable and durable packaging outweigh the benefits of dematerialization. By using fully recyclable materials in reusable packaging, a reduction of up to 74% in environmental impacts can be achieved compared to packages with resource-intensive materials. Similarly, Cottafava et al. (2021) find that all reusable cup options have lower CO_2 emissions than single-use alternatives. Accorsi et al. (2020) explore the implementation of an infinite reusable and recyclable container network within the Italian food industry. By considering container flows and potential variations in packaging demand, they demonstrate how this closed-loop packaging system can lead to profitability and long-term sustainability, as supported Simms et al. (2020).

In a study comparing fruit packaging options in Spain, Abejón et al. (2020) find that a reusable plastic crate outperforms a single-use cardboard box in all impact categories, as shown in the life cycle assessment analysis. Similar findings are observed in e-commerce, where Zimmermann & Bliklen (2020) compare a reusable polypropylene box with a reusable shipping bag against their single-use counterparts (cardboard box and LDPE bag, respectively). The study concludes that reusable systems offer environmental advantages when a certain number of usage cycles are achieved. However, the consumer's role is crucial, as a return rate of over 90% is necessary to achieve eight or more usage cycles. To address the challenges of implementing sustainable packaging practices, Pålsson et al. (2013) propose a model that compares the environmental and economic impacts using criteria such as CO_2 emissions and costs, respectively. They conduct a case study involving Volvo Car Corporation and Volvo Logistics, comparing one-way packaging with returnable packaging. Based on criteria including packaging fill rate, packaging material, transport, material handling, waste handling, and administration, the study concludes that one-way packaging yields better results in both environmental and economic aspects.

The last-mile delivery poses significant challenges for e-commerce companies, particularly in terms of delivering lightweight packages at competitive costs. Yu et al. (2016) use IKEA as an example, highlighting the company's focus on encouraging customers to pick up their purchases in-store. This is made possible by IKEA's flat packaging design, which allows for easy transportation by car. However, IKEA still offers home delivery as an option, albeit at a higher distribution fee. Morganti et al. (2014) present two solutions for last-mile delivery: automated parcel stations with lockers and pick-up points. Moroz & Polkowski (2016) also mention parcel machines as another automated option for collection and dispatch of consignments at any time.

Koskela et al. (2014) emphasize the role of delivery systems in determining the environmental impact of different options. Contrary to previous studies, when comparing a reusable plastic crate with a recyclable cardboard box, a recyclable option performs better in terms of environmental impact across all categories in a LCA comparison. However, it is noted that an effective recycling system is necessary for this outcome to be achieved. (Pålsson & Olsson, 2023) indicate in its review article that regarding reusable packaging the largest category studied are take-away packages (22 articles), transport packaging (18 articles) and beverage packaging (18 articles). There is no specific article considering DIY products, however, generally, the majority of products packaged can be included in the transport packaging category. To consider that all the reusable packaging strategies analysed were operating in a closed loop network.

In terms of eco-design, Bassani et al. (2022) conduct a LCA analysis of pharmaceutical packaging and conclude that it is possible to design more compact packages that reduce empty spaces, thereby saving materials and costs. Escursell et al. (2021) mention RePack as an alternative to cardboard boxes, which helps minimize waste. RePack utilizes a reusable PP bag and can reduce CO_2 emissions by up to 80% compared to disposable cardboard boxes. The empty boxes are required to be returned through a post office. Scudopack is also mentioned as a viable alternative to bubble wrap or film, specifically for protecting furniture and windows. Scudopack can reduce volume by up to 70%. A comparison between the research findings and the present work is presented in ***Table 7*****,** providing an overview of the discussed topics.

Table 7. *A comparison between works searched and this work.*

Paper	Approach			Level of Packaging			Dimensions			Material		
	RC	RE	RT	1	2	3	EC	EV	SO	PL	PP	NS
(Escursell et al., 2021)	X	X	X		X	X	X	X		X	X	
(Pålsson et al., 2013)	X	X			X	X	X	X				X
(Herbes et al., 2018)	X	X			X				X			X
(Lu et al., 2020)			X		X			X	X			X
(Coelho et al., 2020)		X		X	X	X		X		X	X	
(Accorsi et al., 2020)		X			X			X		X		
(Gardas et al., 2019)		X			X	X		X				
(Glock & Kim, 2014)		X			X	X		X				
(Cobb, 2016)		X			X	X		X				
(D. A. L. Silva et al., 2013)		X		X	X	X	X	X				X
(Gatt & Refalo, 2022)	X	X			X			X		X		
(Cottafava et al.,2021)		X		X				X		X	X	
Simms et al., 2020)			X	X	X			X	X			X
(Abejón et al., 2020)	X	X		X				X		X	X	
(Zimmermann & Bliklen, 2020)	X	X					X	X		X	X	
(Yu et al., 2016)		X	X	X	X	X		X	X			X
(Moroz & Polkowski, 2016)			X	X	X	X		X	X			
(Koskela et al.,2019)	X	X			X	X		X		X	X	
(Cottafava et al., 2021)			X	X			X	X				X
This Work	X	X	X	X	X		X	X		X	X	

Legend:

RC – Recycling; **RE** - Reuse; **RT** - Rethink**; 1 -** Primary**; 2** – Secondary**; 3-** Tertiary; **EC** – Economic.
EV- Environmental**; SC**- Social; **PL**-Plastic; **PP**-Paper**; NS**- Not specified.

3.4. Chapter Conclusions

The e-commerce industry has been rapidly evolving, and companies must adapt quickly to meet customer needs. Existing literature emphasizes the importance of buyer satisfaction for success in this field. Factors such as trust, brand recognition, and past buying experiences carry more weight in the purchasing decision than product price. 3PL is a common approach employed in B2C e-commerce as a means to streamline processes along the supply chain. It is generally accepted that 3PL is more cost-effective than SRL in most cases. To enhance the customer experience, the omnichannel approach has been widely advocated, allowing for synergies between physical and online channels.

CE has been a topic of discussion for decades and is a key pillar for the EU. With the EU's proposal of a new directive, reusable packaging gains greater importance in the packaging landscape. CE is closely linked to the concept of reuse, and many authors suggest that eco-design and recycling are crucial for achieving a successful circular economy. The ReSOLVE framework, developed by the Ellen MacArthur Foundation (2015), is widely accepted as a means to implement CE. Implementation of this economy has proven to reduce CO_2 emissions at various levels of the supply chain, with the LCA methodology being commonly used to quantify these impacts.

The study of packaging is generally divided into two main categories: its material composition and packaging strategies. The primary materials used in packaging are paper and plastic. Plastic is often considered a better option for reuse, while paper is seen as a more sustainable choice for recycling. In terms of long-term environmental impacts, reuse is generally regarded as a better option, as indicated by Cottafava et al. (2021) and Zimmermann & Bliklen (2020). Rethink is often connected to one of the other two options and is closely associated with the eco-design approach. The majority of studies on reusable packaging focus on the food sector and consider closed-loop supply chains, as highlighted by Pålsson (2013). Consequently, most of the analysed papers only consider environmental impacts. This dissertation aims to develop a standardization method for allocating products to specific packages, with the goal of minimizing environmental impacts, packaging costs and materials consumptions The LCA methodology, widely used in previous studies, will be employed. Only two papers have addressed packaging in the context of e-commerce (Escursell et al., 2021; Zimmermann & Bliklen, 2020), and an in-depth analysis in the DIY market is yet to be conducted.

4. Methodology

This chapter shows the methodology used to approach the problem presented in **chapter 2**. **Section 4.1** delineates the framework proposed, including the definition of the different analyses' boundaries. Subsequently, in **section 4.2** the data collection process is presented. Moreover, **section 4.3** defines the proposed scenarios for the analyses. The methodology utilized for calculating materials consumptions and costs for each package is presented in **section 4.4**. Furthermore, the employment of the LCA analysis is explained in **section 4.5.** Lastly, in **section 4.6** some conclusions of the chapter are presented.

4.1. Framework

The methodology adopted (***Figure 11***) is centred on economic and environmental criteria. An analytical framework was used to approach these criteria, which were based on the problem described in **chapter 2** and previous works presented in **chapter 3**. The selection of this framework was influenced by the work of Pålsson et al. (2013) in which economic and environmental criteria were considered in the packaging context. To ensure a systematic and logical progression, a step-by-step approach was employed to better address the problem in hand, since each step of the framework is linked with the conclusion of the previous one.

Figure 11. *Dissertation step-by-step approach*

1. Definition of Objectives: The first step was to define the objectives to be achieved by implementing this methodology. Three main objectives were considered: Reducing packaging costs, materials consumptions, and environmental impacts. Thus, given the lack of standardization in the packaging process, it was necessary to carry out one for LMPT´s online packaging operations. Furthermore, this standardization should be oriented towards the optimization of the defined objectives.

2. Data Collection: Data on packages' costs, weight, allocation, and material composition was obtained through: (1) LMPT documentation, (2) direct observations at the Porto Alto warehouse, (3) previous studies done in the packaging context and (4) packaging suppliers' information. When possible, the data from (1) and (2) were always prioritized since it is already contextualized in the company reality. **Section 4.2** presents the data collection process with greater detail.

3. Scenarios Definition: To implement a solution that is consistent with the objectives defined, several scenarios were proposed. The main rationale among the delineation of these scenarios was the disposability of the packages (single use or reusable). The motivation behind the presentation of multiple scenarios is to enable a comparison of various packaging options, thereby facilitating the identification of the most suitable option in accordance with the established objectives. **Section 4.3** has a more detailed explanation of the distinct scenarios and their selection process.

4. Packaging Standardization: As stated in step 1, packaging standardization is not existent in current operations. To address this, the observations obtained at Porto Alto were considered to implement packaging standardization. The key factors for the creation of the standardization were: (1) products dimensions, (2) types of packaging used for each order, and (3) whether the orders had primary packaging or not. The goal of this standardization is to streamline the packaging process while reducing packaging costs, materials consumptions, and environmental impacts. This procedure was followed for both disposable (single use) and reusable packaging.

5.Materials Consumption: The total weight of the packages used in the scenarios to be proposed was considered to determine the consumption of materials, taking in account the unitary weight of each package. Details on the calculation for each package are presented in **section 4.4**.

6.Cost Analysis: Packaging costs were calculated differently depending on whether the option is reusable or not. In the case of single-use packages, only the purchase costs and the green dot value were considered. On the other hand, for reusable packaging options, the reuse cycles and return rates were also taken into consideration, allowing to amortize packaging costs. **Subsection 4.4.7** explains how the costs for each scenario were obtained.

7.Environmental Analysis: For the environmental analysis, the ecoinvent v3 database in SimaPro was used. Beyond global warming (CO_2 emissions), other impact categories are also considered. **Section 4.5** discusses the assumptions used in its modelling.

To facilitate the comprehension of the distinct analyses undertaken, there is a need to delineate boundaries to understand the components included within each analysis, as presented in ***Figure 12***. Accordingly, the evaluations of materials consumptions, environmental impacts, and costs, are aligned with the strategic prerogatives of LMPT explained in **section 2.2**. Regarding the environmental analysis, it is considered the life cycle of each package from the extraction of raw materials until its end of life. This strategic choice of boundaries allows to execute a comprehensive LCA to the packaging materials. For the packaging consumption and costs, it is only considered elements that are in LMPT's control, i.e., from the moment that the packages are bought from the supplier, until they are delivered to the customer. However, if the packages are reusable, it is kept track of the packages until they are no longer possible to be used, or if the customer does not return the packages.

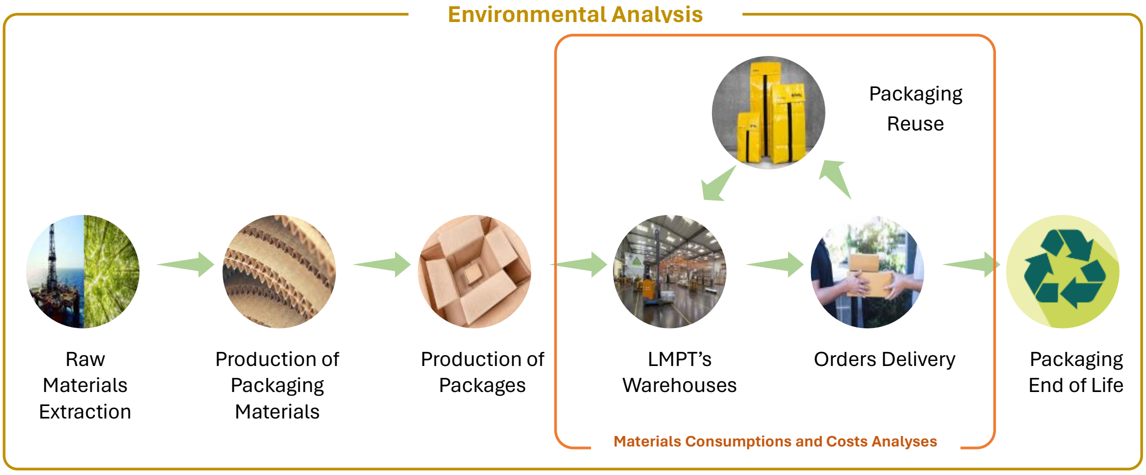


***Figure 12.** Dissertation's Analyses Boundaries*

4.2. Data Collection

The data collection process is an essential step to gather and organize information allowing the implementation of the framework proposed. Different sources of data were used according to the type of data needed to approach the problem: For baseline, the observations made were used to understand how products were allocated to packages, the direct measurements to know the weight of each package and the costs were given by LMPT; For the scenarios to be proposed, the weights and costs were obtained by consulting packaging suppliers. The materials for both packages were either obtained from the supplier website or from literature. If possible, it was always used data available from LMPT documentation. However, it was necessary to use external sources or make observations as some of the data required to perform the analyses were not available. Given the lack of information on how packaging was allocated to each type of product and the need to define the baseline configuration, observations had to be made to comprehend how each product was packaged.

The observations were conducted at Porto Alto's warehouse between 20th June and 30th June of 2023. During this period, eight days were considered (from Tuesday to Friday, for two weeks). On the weekends the warehouse does not operate so no observations were registered. On Mondays, it was asked by the operators to not track the packaging used for each order since it is a day with a high work volume due to the orders placed during the weekend. In order to collect data from the observations, a grid was made available for operators to fill in considering the packaging used. A sample of the grid used to collect observations is available in **A.3.1.** For each order, the number of packages used was recorded, with the exception of adhesive tape, stretch film, bubble wrap and corrugated cardboard, which was requested that, if used, to insert the value of "1", since quantifying each of these types of packaging would imply an extra workload for operators (the weighting all of these packages beforehand would be inconvenient for the operators and would significantly extend the time required to complete the packaging operations). To facilitate identification, the terms "small", "medium" and "large" were used to identify the boxes and envelopes.

Regarding the weights of packages currently used, a direct measurement was carried out at the Porto Alto warehouse while the cost of each package was provided by LMPT. The package's material composition was determined by referencing the values provided on the suppliers' websites, whenever such information was available. For the stretch film, bubble wrap and corrugated cardboard, the materials that are generally used in its composition were considered, according to the existing literature. Considering the packaging introduced in the different scenarios to be presented, the values (weight, packaging material and cost) were taken directly from the websites of the suppliers of these products (RePack, Hipli, RajaPack and Noissue). The respective values can be found in **A.1.1.**

Considering the environmental analysis, the values used are the ones presented in the ecoinvent v3.3 database in the SimaPro software.

4.3. Scenarios Definition

4.3.1. Proposal of New Packaging Materials

In the formulation of the different scenarios, a range of packaging materials distinct from those currently used in the LMPT packaging operations were presented. The emphasis was placed on standardizing the external packaging materials, such as film, bubble wrap, and corrugated cardboard, while exploring reusable alternatives for boxes and envelopes. **A.1.2** presents the material composition for all the packages used.

Envelopes:

Currently, two types of envelopes are used in LMPT's online packaging operations. One serves for product protection, while the other contains essential shipping information. Both types of envelopes are retained for scenarios where the packaging is manual. The first type is preserved because the majority of products can be accommodated within envelopes, particularly since most of the items shipped are of small volume (fit inside an envelope). The second type contains shipping information, so it is indispensable for the operators who deliver the products.

While the incorporation of a QR code may seem like a potential solution to eliminate the second envelope, the risk of it being damaged during shipping, making it unreadable for both operators and customers, led to its exclusion from the implementation of the various scenarios. Thus, the shipping envelopes were maintained, as the envelope must have a visible part so that the order information can be viewed by the operators who perform the shipping of the orders. However, shipment envelopes were not considered in the analysis since the quantities are the same for all the scenarios.

Nonetheless, new envelopes with two distinct properties were proposed. One where the envelope would be reusable, and another where the envelope's materials are compostable.

For the reusable envelopes, the RePack option was considered, as discussed by Escursell et al. (2021). According to their research, these envelopes have the potential to reduce waste and CO_2 emissions by up to 80%. Additionally, RePack claims that these envelopes can be used from 20 to 40 times. Furthermore, the reusable envelopes feature larger dimensions compared to the current ones, enabling a larger range of products to be accommodated within envelopes instead of boxes. This shift aims to optimize the use of boxes, which will be primarily reserved for heavier and larger products. The reusable envelopes are crafted from recycled PP, a material that is recyclable and reusable (***Table 6***). This choice aligns with the EU's objectives for reusable packaging, which seeks to have 30% of packages designated as reusable by 2030.

For the use of disposable envelopes, an option was looked to replace the envelopes currently used, consisting of LDPE (inner packaging) and paper (outer envelope). It was decided to use the *Noissue* compostable envelopes as they can be compostable between 90 and 180 days (Noissue, 2022). In addition, this option allows the customer who receives the order to reuse the package once more, as it comes with two stickers that seal the envelope (one for each use).

Boxes and Filling Packaging:

In the current packaging configuration, cardboard boxes of two different dimensions are used, which are discarded after its usage. Both will be maintained for scenarios where single usage boxes are used. To align with environmental considerations and EU regulations, an alternative in the form of reusable boxes made from recycled PP, provided by Hipli, was explored. These boxes will be reserved primarily for heavier products, rather than solely focusing on voluminous items. This distinction is essential as Hipli's boxes hold less volume than RePack envelopes. The decision to retain single-use cardboard boxes was due to the fact that, for single usage, cardboard is environmentally the most efficient option, as presented in **section 3.3**. To optimize the use of these cardboard boxes, the packaging standardization process will evaluate the most efficient way to maximize their package filling rate. Regarding filling packaging materials, used to protect the product, several sustainable options were considered, including materials made from fungi or compostable beans. However, these alternatives were not chosen due to their high costs and less malleable nature. For instance, fungi-based materials are often presented in brick-like forms, which are impractical for the packaging process. Likewise, compostable beans, while environmentally friendly, are very small and might not provide a positive customer perception, especially for large packages. Additionally, their use could generate a significant amount of waste in the packaging area, creating inconvenience for operators. Consequently, these alternatives were not selected.

External Packaging:

External packaging includes all the packages that do not have a fixed measure, i.e., given an order, the amount of the packaging used is variable. So, external packaging encompasses: Bubble wrap, corrugated cardboard, stretch film, kraft paper and kraft bubble.

Efforts were directed toward standardizing external packaging materials in this dissertation, with a focus on achieving a consistency in the packaging process. Reusable alternatives were not explored, as the available market options predominantly serve the purpose of tertiary packaging. The objective of this dissertation is to employ external packaging as secondary packaging. As such, the materials to be standardized encompass stretch film, corrugated cardboard, and bubble wrap. In terms of packaging methodology, the choice between bubble kraft and kraft paper is contingent upon the product's dimensions. Specific dimension criteria were established during the standardization process to delineate when each material should be used. It is important to note that the preference for kraft paper over plastic alternatives, such as PP and PE was driven by sustainability considerations, particularly in single-use scenarios, as exposed in **subsection 3.3.2**. Consequently, the selection of paper-based materials, specifically kraft paper and kraft bubble paper, was made, with sourcing from *RajaPack.*

4.3.2. Description of the Proposed Scenarios

The definition of scenarios was guided by the comparative analysis between reusable and disposable options presented in **subsection 4.3.1**. Consequently, four distinct scenarios were considered for comparison with the baseline configuration. The latter seeks to replicate the current packaging configuration within LMPT's e-commerce operations. The four scenarios aim to address the issue of overpackaging, a concern highlighted in previous research by Escursell et al. (2021) and Lu et al. (2020).

Scenario 1 maintains all packages as disposable, and already includes standardization, making it the simplest option to implement, involving changes only in packages' materials. Additionally, as argued by Koskela et al. (2014), recyclable systems may hold advantages in certain scenarios, so the implementation of a disposable scenario yet, with recyclable materials, was logical. Scenario 2 features reusable boxes and envelopes, a choice favoured by the majority of studies analysed due to its positive environmental and economic implications (Abejón et al., 2020; Accorsi et al., 2020; Coelho et al., 2020; Gatt & Refalo, 2022; Pålsson et al., 2013; D. A. L. Silva et al., 2013; Zimmermann & Bliklen, 2020). However, the scenarios containing reusable packages will be more challenging to implement, as LMPT's e-commerce operations are not designed to accommodate reusable packages. Thus, there was a need to describe the logistic structure so that these packages could be implemented. Scenario 3 represents a mixed approach, encompassing both single-use and reusable packaging elements. This scenario aligns with the objective of incorporating 30% reusable packaging, aiming to meet minimum sustainability targets set by EU. Scenario 4 introduces process automation through computer vision, optimizing packaging space when packing products. In this case, only single-use packaging is considered. External packaging materials are uniform across scenarios 1, 2, and 3. Scenario 4, however, does not incorporate external packaging. ***Table 8*** presents all the packages used in each scenario.

Table 8. *Packages used in each scenario.*

<table>
<tr><th>Baseline*
Only single-use</th><th>Scenario 1
Only single-use</th><th>Scenario 2
Only reusable</th><th>Scenario 3
Mixed</th><th>Scenario 4
Automated</th></tr>
<tr><td colspan="5">Boxes</td></tr>
<tr><td colspan="2">Small (Current); Medium (Current); Large (Current)</td><td colspan="2">Small Reusable; Medium Reusable; Large Reusable</td><td>Cardboard Box</td></tr>
<tr><td colspan="5">Envelopes</td></tr>
<tr><td>Small (Current); Medium (Current); Large (Current)</td><td>Small Compostable; Medium Compostable; Large Compostable</td><td>Small Reusable; Medium Reusable; Large Reusable</td><td>Small Compostable; Medium Compostable; Large Compostable</td><td>Not Used</td></tr>
<tr><td colspan="5">External Packaging</td></tr>
<tr><td>Corrugated Cardboard; Stretch Film; Bubble Wrap; Tape</td><td colspan="3">Kraft Tape; Bubble Kraft; Kraft Paper</td><td>Not Used</td></tr>
</table>

*The baseline configuration also includes mirror boxes and filling paper.

<u>Baseline:</u>

In the baseline packaging configuration only disposable packages are used: For envelopes three dimensions are used made from LDPE and paper; For boxes, two dimensions made from cardboard are considered, and inside of them, filler paper can be used. Three dimensions from mirror boxes are also contemplated, being used only for mirrors. These are exclusively used in this packaging configuration. For external packaging, bubble wrap, corrugated cardboard and stretch film are used. The tape used to seal packaging, is made from PP. There is no packaging standardization, so each operator packages orders in a different manner. By implementing this configuration, the objective is to replicate current packaging operations.

<u>Scenario 1 – Only Single Use:</u>

In this scenario, the change is only in the materials used. This scenario has been considered since the operators are already familiar with the operations performed. The minor changes to be made are related to the standardization in the packaging process, which is common to all three scenarios with manual packaging. Therefore, the current structure is maintained. However, considering the EU's objectives, this scenario will always be presented as a transitional scenario, as 30% of the packaging must be reusable by 2030. Furthermore, since all the packaging is single use, there is no need to establish any additional considerations regarding operations.

Nevertheless, a scenario in which the materials, although single use, are recyclable, sometimes may be more advantageous to implement than a completely reusable structure. This scenario also includes the inclusion of new suppliers. For boxes and kraft paper, the supplier remains the same. For compostable envelopes, *Noissue* was considered and for external packaging (kraft tape, bubble kraft, kraft paper) *RajaPack.*

Scenario 2 – Full Reusable:

The second scenario introduced the adoption of reusable envelopes and boxes driven by EU's objectives of reusable packaging. Consequently, this scenario was considered. However, LMPT's current operations do not incorporate reusable scenarios, so several changes were necessary. In this scenario, there was a need to consider how these reusable packages would be managed, including aspects such as the packages returning process and the functioning of reverse logistics.

One of the difficulties to consider is how the packaging would be returned. Since order deliveries operate on an open-loop supply chain, control over the packaging is limited. Additionally, another challenge is to find a way to engage customers with the idea of returning the packaging. In order to make the process as convenient as possible for the customer, two alternatives are considered: collecting the packaging at the time of home delivery (return from home) or later return at one of LMPT's physical stores (return on the go), as indicated by Ellen MacArthur Foundation (2020). The cleaning of the packages would be handled by LMPT. For the scenarios that include reusable packages, it was considered that the return rate would be 32% (Statista, 2019). Since there were no values regarding the Portuguese context, it was used the one with worse value (values can be consulted at **A.4.2**). Since Portugal is in the lower performing cluster regarding e-commerce (Bălăcescu et al., 2023). In the case of collection by the distributor, they would be responsible for returning the packaging to LMPT's regional platforms.

Regarding the inclusion of new activities (packaging quality control, maintenance, and cleaning), these would be carried out in LMPT's regional platforms. Packaging is considered to be of good quality if it is in a condition to be reused. If the packaged is reusable, it should be cleaned. Otherwise, it would be disposed (***Figure 13***).

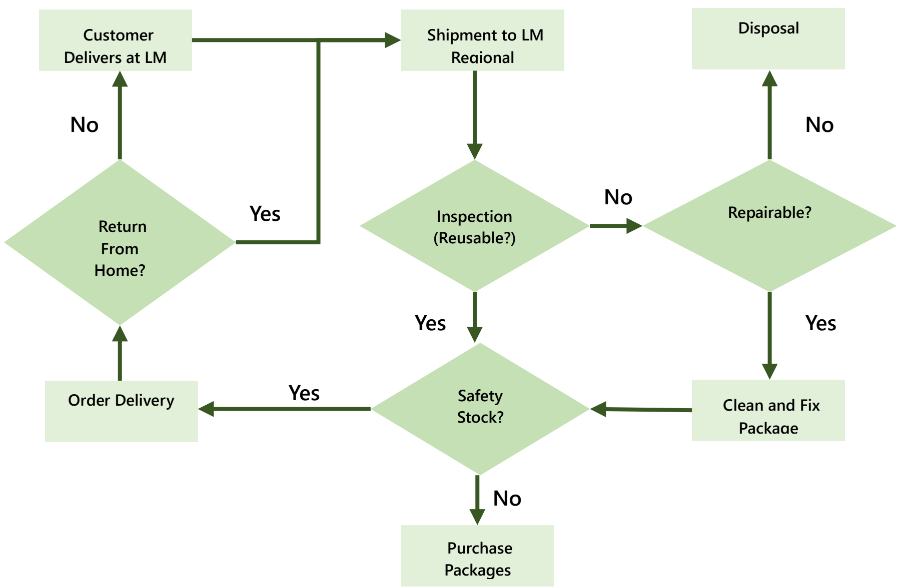


Figure 13. *Logistic Structure for Reusable Packages.*

Scenario 3 – Mixed:

Scenario 3 includes a mixed solution, meaning that includes both reusable and single-use packages. The choice was made to use compostable envelopes and reusable boxes. This combination was chosen because compostable envelopes have dimensions similar to the envelopes currently used in LMPT's online operations. The option to use reusable envelopes and single-use boxes was not considered because the envelopes have dimensions similar to those of the boxes, which would have led to the exclusive use of envelopes. The logistics system for reusable packaging follows the same structure as presented in Scenario 2 (***Figure 13***).

Scenario 4 – Automated:

Scenario 4 employs automation for the packaging problem, using a solution provided by Sparck Technologies. This option allows for fit-to-size packaging, ensuring optimal use of space and eliminating overpackaging issues, thereby eliminating the need for additional filler material. By using this machine, orders with multiple products can be packaged, with the packing time ranging from three to seven seconds. The machine includes a corrugated cardboard feeder, which is used to package the products. Operators place the products into the machine, which are subsequently scanned to determine the minimum dimensions required to accommodate the order (Sparck Technologies, 2021).If the products are considered too large (as it will be explained in **section 5.1**), they will not be packaged. In this scenario, there are only two packaging options: cardboard (that is used in boxes) or no package.

Figure 14 summarizes the packaging scenarios described :

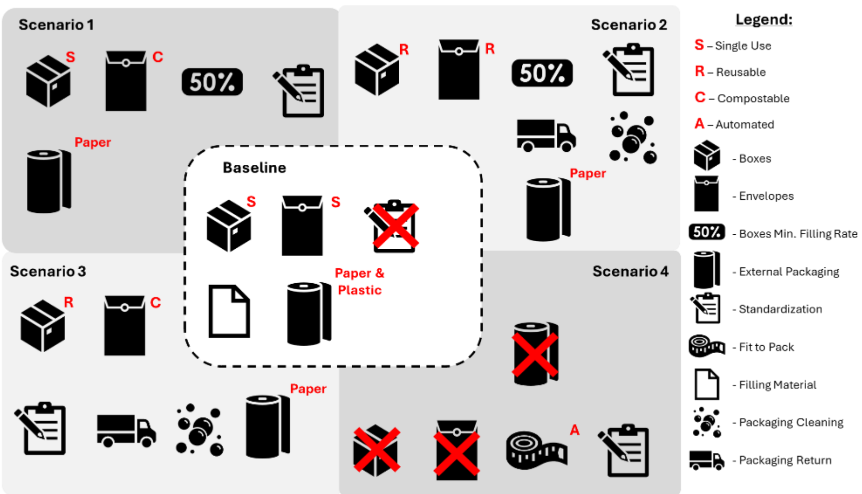


Figure 14. *Packaging scenarios summary.*

4.4. Materials Consumption and Packaging Costs

Due to a lack of data on the weight of the materials used in the packaging processes, there was a need to compute the weight of the packages in a uniform manner. To do so, for each observed order it was considered: (1) the total number of products, (2) the total number of SKUs, (3) the volume and area of each product, (4) which packaging was used, (5) the filling rates for each package, i.e., how much of an envelope or box is filled with products and (6) whether or not the products in these packages had primary packaging.

4.4.1. Order Composition

For each observed order in the period of 20th June to 30th June 2023, it was registered the section of each product, their respective quantities, and if there was at least one product with primary packaging. Thus, the total volume (eq.1), weight (eq.2), and area (eq.3) of an order were computed. In order to standardize the calculation form, it was assumed that all products within an order were prisms. The measurement of the dimensions of the order were considered in the following way: It is considered the largest dimension in all products, and then the second and third dimensions are summed. For instance, consider an order with three products that have respectively: 10 cm,9 cm and 8 cm; 7 cm,6 cm, and 5 cm; 4 cm,3 cm, and 2 cm. Consequently, the order dimensions would be 10 cm,18 cm and 15 cm.

$$\textbf{Volume of an order} = \sum_{i}^{NP} L_i \times W_i \times H_i\ ,\ \ L_i\ , W_i\ ,\ H_i > 0 \quad (1)$$

$$\textbf{Weight of an order} = \sum_{i}^{NP} WW_i\ \ ,\ \ WW_i\ , > 0 \quad (2)$$

$$\textbf{Area of an order} = \sum_{i}^{NP} 2(L_i \times W_i) + 2(L_i \times H_i) + 2(W_i \times H_i)\ ,\ \ L_i\ , W_i\ , H_i > 0 \quad (3)$$

Where NP corresponds to the number of products in an order; L_i the length of product i; W_i the width of product i; H_i, the height of the product i; WW_i- the weight of product i ; i to the i-th product of an order.

4.4.2. Filling Rate of an order

To determine whether the packages were being used efficiently, i.e., the box/envelope has its capacity used the most possible, the filling rate of each package was calculated (eq.4). It was also considered that all the products of a given order would be included in the package. However, for the current packaging configuration, if more than one package was used and since there was no information on how the products were distributed, the products were allocated in a manner that the packages filling rates would be less than 100%. If the filling rate was greater than 100% and the order included multiple products, the larger product was considered to be outside the box/envelope. In cases where the filling rate was always greater than 100%, i.e., even with the larger product outside the package, instead of the computed value, it was considered the average of the filling values between 0% and 100% of the remaining orders. The average was chosen to not influence the average filling rates overall values for each scenario. However, this problem only occurs for the baseline configuration, and it may happen due to wrong filling of the grill by the operators, wrong product dimensions or the sum of the volumes do not follow eq.1, especially for products where the volume is far from a prism form. For instance, several vases, embedded in each other will not follow eq.1, since various products do occupy the same space within the package (***Figure 15***).

$$\textbf{Filling Rate for an order} = \frac{\text{Volume of the order}}{\text{Volume of Package Used}} \times 100 \quad (4)$$

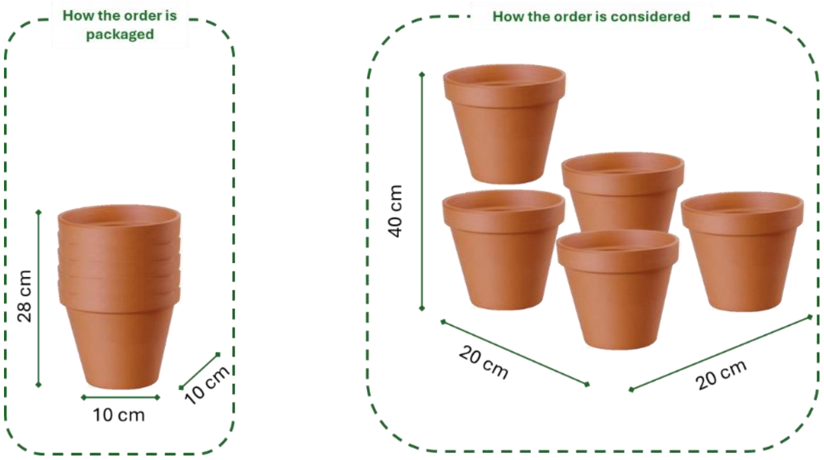


Figure 15*. Example of order volume calculation limitations.*

4.4.3. Total Weight of Boxes and Envelopes

The total weight of the packages was considered for each scenario. Because boxes and envelopes had previously measured weights, it was only needed to multiply the number of packages present in each order by the weight of the boxes (eq.5) and envelopes (eq.6).

$$\textbf{Boxes Weight for each scenario} = \text{Weight}_{small\ Box} \times \#\text{Small Box} + Weight_{Medium\ Box} \times \#\text{Medium Box} + Weight_{Large\ Box} \times \#\text{Large Box} \quad (5)$$

$$\textbf{Envelopes Weight for each scenario} = \text{Weight}_{small\ Envelope} \times \#\text{Small Envelope} + Weight_{Medium\ Envelope} \times \#\text{Medium Envelope} + Weight_{Large\ Envelope} \times \#\text{Large Envelope} \quad (6)$$

4.4.4. Filling Material

Based on the observations done, the filling paper was only used in boxes. Because the weight of filling paper for each order could not be obtained, the starting point was the total weight of a filling paper package. Following that, the area that a filler paper package could cover was calculated. Because there was no information on the paper thickness, it was assumed to be 5 µm, the same as usual sheet of paper. As a result, the total volume that filling paper could fill was calculated as well as its density. To compute the amount of filler in each package (eq.7), it was assumed that the filler would fill the area not occupied by products, but only where the filler was used, i.e., using a box does not imply the use of filling paper, but its use does imply the existence of a box. The filling material was only considered in the current packaging configuration.

$$\textbf{Weight of filling Material} = (1 - Filling\ Rate) \times Volume\ \ Package \times \rho_{Filling\ Material} \quad (7)$$

Where $\rho_{Filling\ Material}$ corresponds to the density of the filling material.

4.4.5. External Packaging and Tape

For corrugated cardboard and stretch film, a similar approach to filling materials was employed. To determine their weight, it was considered that both enveloped the product's area twice. This conclusion was derived from observations made during the packaging process at the Porto Alto warehouse. For the baseline configuration it was considered that when external packaging was used in an order, it was applied universally to all products within that order. Although this diverges from actual practice, this methodology was used since it was not possible to know to which product the package was allocated to. For the proposed scenarios, the external package will follow the guideline proposed in the standardization process. For the calculation of weights of external packaging (eq.8) and tape (eq.9), both were assessed by their total volume weights, following the same reasoning made for filling paper. Considering the orders dimensions, the area covered by each packaging was calculated, along with its corresponding weight.

$$\textbf{Weight of External Packaging} = 2Area_{order} \times \rho_{External\ Package} \quad (8)$$

$$\begin{aligned}\textbf{Weight of Tape} = {} & \mathrm{Width}_{Tape} \times \mathrm{Width}_{Box} \times Height_{Box} \times \rho_{Tape} \\ & + \mathrm{Width}_{Tape} \times \mathrm{Width}_{Order} \times Length_{Order} \times \rho_{Tape}\end{aligned} \quad (9)$$

Where $\rho_{External\ Package}$ is the density of the external package material and ρ_{Tape} is the density of the tape material.

4.4.6. Packages Filling Rates

For each scenario it was evaluated how the filling rate of a package was connect with the section of a product, the weight of an order, the volume of an order and the type of package used. The use of external package was considered to have a 100% filling rate.

Filling Rate and Product Section: For each existing section, how much the SKUs of a given section occupy the packaging to which it was allocated, to understand if the allocation of packages is related with some section or if there is any section responsible for the use of a specific package.

$$\boldsymbol{FRPS} = \frac{Number\ of\ products\ packed\ within\ the\ filling\ range}{Number\ of\ products\ packed\ in\ \text{a given}\ section} \quad (10)$$

Filling Rate and Order Weight: Considering the total weight ranges of an order how much the SKUs of a given weight range occupy the packaging to which it was allocated.

$$\boldsymbol{FROW} = \frac{Number\ of\ orders\ packed\ within\ the\ filling\ range}{Number\ of\ orders\ packed\ within\ the\ weight\ range} \tag{11}$$

Filling Rate and Order Volume: Considering the total volume ranges of an order, how much the SKUs of a given volume range occupy the packaging to which it was allocated.

$$\boldsymbol{FROV} = \frac{Number\ of\ orders\ packed\ within\ the\ filling\ range}{Number\ of\ orders\ packed\ within\ the\ volume\ range} \tag{12}$$

Filling Rate and Order Package: Considering the type of packaging used, what is the filling rate that each package has on average.

$$\boldsymbol{FROP} = \frac{Number\ of\ orders\ packed\ within\ the\ filling\ range}{Number\ of\ orders\ packed\ with\ a\ given\ package} \tag{13}$$

4.4.7. Packaging Costs

For packaging costs, in the case of single-use packaging, only the cost of purchasing the package from the supplier was considered, which was then multiplied by the quantities or weight used. Regarding the reusable packages, in addition to the purchase costs, it was considered also the reusable cycles and return rates. By including these two factors, it was possible to amortize the value of a package within each usage. For the automated option, only the cost of the cardboard and tape was considered, as the cost of implementing the machine would cause an increase in costs in the short term, making its comparation with other scenarios unfeasible. For the cost analysis of this scenario, it was considered that the investment is already paid, which would not be true. The green dot value is included in all the scenarios, considering the weight of packaging materials consumed. The total costs for each scenario will be obtained according to the formulas available in **A.4.1.**

4.5. Life Cycle Assessment

The LCA was performed according to ISO14040, and ISO14044 (ISO, 2006) and it is composed by four main steps: goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation. The LCA was conducted with SimaPro 9.1 software and using the Ecoinvent v3.3 database.

4.5.1. Goal and Scope Definition

The goal and scope definition are the first step in the LCA, serving as the basis for guiding the entire assessment. The primary goal to be achieved with this assessment is specified, the environmental boundaries are defined, and the functional unit is the determined. A functional unit defines the quantity of the product being studied, creating a calculation basis for comparing different analyses, considering the function of the object of study. Two environmental boundaries are considered in this assessment: cradle to cradle, which considers products that can be completely recycled, where all of its components are used to feed another product, earth, or become fuel, resembling the nature's cycle; and cradle to grave, which considers the products from the moment that its raw materials are extracted until its disposal.

The goal of this analysis is to evaluate and compare the yearly environmental impacts of the different cradle to cradle packages for reusable packaging, and cradle to grave packages for single use packaging, in the current operations baseline configuration and in the scenarios proposed at **Section 4.3.** The functional unit used is "the number of packages usages cycles in one year". The selection of this functional unit is due to the fact that one of the objectives of this dissertation is to compare different environmental impacts in each scenario proposed, under the same customer demand. The system boundaries are the ones presented in **Figure 12**, from materials extraction until packages' end-of-life. It was used the cut-off allocation approach since the primary production of a material is always allocated to the first user, so if the material is recycled the first user does not receive the credit of the material being recycled. Since this was considered the most approximate of how LMPT packaging works, the abovementioned allocation approach was chosen.

4.5.2. Life cycle inventory

The second step of the LCA consists in the collection of the inventory associated with the baseline configuration and each scenario analysed (e.g., kilograms of CO_2 emitted). To determine this inventory, the baseline configuration and each scenario was modelled in SimaPro using references from the Ecoinvent v3.3 database (please consult **A.5.1**). Several assumptions were made in the formulation:

- For Single Use boxes, Corrugated Cardboard, and all Kraft Paper packaging, were considered references that already include the packaging material production, so a single reference was chosen to do the modelling;
- For the remaining packages, the modelling starts at the packaging material production and all the products consolidations always included electricity, to simulate the making of the final product. For instance, to obtain a reusable envelope it was considered PP and electricity. Of course, this is an approximation, and other products are indeed used for the production of envelopes. However, for simplification, this was not considered. The same reasoning was done for the remaining packaging;
- In the process of product transformation, it was considered that mass was conserved;

- For the compostable envelope, all the bioplastics (PLA and PBAT) were considered to be PLA, since there is no PBAT reference in the Ecoinvent database;
- The only transportation considered was the one from the suppliers to the LMPT warehouse at Porto Alto. For the reusable packages it was also considered the transportation from the LMPT stores to the corresponding Logistics Platform;
- The transportation distance of returning the packages to the logistic platforms was considered to be 225 km, which corresponds to the largest distance between a logistic platform and a LMPT physical store (Lisbon Platform – Castelo Branco LMPT store);
- For the cleaning process of the reusable packages, it was considered to be manual and only included water and soap. For each package it was considered to be used 500 mL of water and 2mL of soap;
- It was considered a return rate of the reusable packages of 32% and reuse cycle of 20 usages;
- To the number of orders observed, it was increased 40% considering that Mondays were not counted in the observations. This value was based on information provided by LMPT;
- For the packages end of life, it was made the division between plastics, paper, and compostable substances. According to *Associação Portuguesa do Ambiente* (APA), about 34% of the packaging plastics are recycled and the remaining either go to landfill or are incinerated. For paper, about 66% of the packaging papers are recycled and the remaining either go to landfill or are incinerated as well (APA, 2023).The water and soaps were considered that 100% would go to the sewers;
- The division in products disposal was define by the reference chosen in the SimaPro software. Accordingly, for both plastics and paper it was considered that the materials would be treated in the following manner: 1% of open burning, 69% of sanitary landfill, 30% of municipal incineration;
- For the electricity values, the same was considered for all the products involving plastic. The machine was considered to have 250 kW and a production capacity of 250kg/h. For the paper products it was considered that the machines would have a power of 80 kW and a production capacity of 1920 kg/h.
- The transportation to packages end of life was not considered since it is depended on where the package is delivered, and it is outside of LMPT control;
- To simulate the presence of recycled PP in reusable packaging, it was used a reference of recycled LDPE, since there was no reference regarding recycled PP on ecoinvent database. LDPE was chosen since it was the closest option available considering recycled plastics.

4.5.3. Life cycle impact assessment

The LCIA is the third step of the LCA. This step consists of converting the inventory collected in the previous step into environmental impacts using an LCIA method. In this dissertation, the LCIA method chosen for the comparation between scenarios is ReCiPe, since it is representative for a global scale and “provides a state-of-the-art method to convert life cycle inventories to a limited number of life cycle impact scores on midpoint and endpoint level" (Huijbregts et al., 2017) . The cultural perspective used was the Hierarchist, since it is the one that seeks conscientious, considering a 100-year timeframe (Goedkoop et al., 2013). This method considers the following 18 impact categories: Global warming (CO_2 eq.), Fine particulate matter formation (PM2.5 eq.), Fossil resource scarcity (oil eq), Freshwater ecotoxicity (1,4-DCB.), Freshwater eutrophication(P eq),Human carcinogenic toxicity (1,4-DCB), Human non-carcinogenic toxicity (1,4-DCB), Ionizing radiation (co-60 eq.), Land use (crop eq.), Marine ecotoxicity (1,4-DCB),Marine eutrophication (N eq.), Mineral resource scarcity (Cu eq.), Ozone formation, Human health (NOx eq.), Ozone formation, Terrestrial ecosystems (NOx eq.),Stratospheric ozone depletion (CFC11 eq.), Terrestrial acidification (SO2 eq.), Terrestrial ecotoxicity (1,4-DCB), Water consumption (m^3).Besides allowing to determine the results of the aforementioned impact categories, ReCiPe also allow the calculation of the single score associated with the baseline configuration and the four scenarios considered. The single score represents the overall environmental impact of the system(s) under analysis. The lower the single score, the better the environment performance is, that is, it is more environmentally friendly. With the obtention of the single scores it was then possible to compare the overall environmental performance between scenarios and baseline.

4.5.4. Interpretation

The final step of the LCA is the interpretation. This step consists of interpreting the results of the analysis taking into account the goal defined in the first step of the LCA. In this thesis, the goal of the LCA is to evaluate and compare the environmental impacts of the scenarios proposed and the current baseline configuration (see **subsection 4.5.1**). Hence, the focus of this step is on the comparison between the overall environmental performance of the baseline configuration and the four scenarios. This comparison was accomplished using the single scores obtained in the previous step.

However, it is also convenient to look at the different impact categories to understand if there are some categories that have a higher influence on the overall performance of a package option. So, a comparation between the same impact categories within different packaging options was also performed. A higher focus should be made on the global warming category, since it translates on CO_2 emissions, which its reduction is one of the main focuses of LMPT.

4.6. Chapter Conclusions

The methodology to be implemented intends to analyse, for different packaging configurations, the packaging costs, materials consumptions, and environmental impacts. To do so, it was implemented an analytical framework done in a step wise manner. Thus, several scenarios are defined allowing to combine different packaging configurations (Single-Use, Reusable and Automation). To obtain results, it was necessary to measure the weight of the packages and its costs. To compare the environmental performances of each scenario, a LCA was conducted, using the SimaPro software, where cradle-to-cradle, and cradle-to-grave boundaries are considered to evaluate the impacts of the packages.

5. Discussion of Results

In this chapter the results obtained from the methodology described in **chapter 4** are discussed. **Section 5.1** shows the results from the observations made at the Porto Alto warehouse. In **section 5.2** the guidelines for the packaging processes are indicated and explained. **Section 5.3** presents the results obtained in the current packaging configuration (baseline). **Section 5.4** presents and compares the scenarios proposed regarding packaging costs, materials consumptions, environmental impacts, and average packaging filling rates with the baseline. In **section 5.5** sensitivity analyses are performed in some esteemed parameters. **Section 5.6** presents conclusions of the chapter.

5.1. Porto Alto Observation Results

From the observations at the Porto Alto warehouse, a total of 242 orders were observed. However, eight of them were not considered since there were no information on its composition at the moment that the database with the orders was consulted. So, all the analysis and results obtained were based on 234 orders. At ***Figure 16***, some general information is presented on the observed orders composition.

In the observations made there is a total of 499 products and 298 SKUs considered. The most ordered products are in section 9 which correspond to the garden product section. Section 3 (comfort) is the only that has more SKUs without primary packaging than ones with. So, when considering packaging, this can be a problematic to save packaging materials, since they do not come packed from the supplier and will need to be packed in LMPT's warehouses. However, the remaining 12 product sections have more or equal SKUs with primary packaging. Therefore, this should help to save packaging materials, and would be expected that there are less packages (in proportion) used in these categories, since they already have packaging from the supplier.

The majority of orders weight less than 5 kg and have a volume lower than 5 dm^3. So, a lot of orders have a lower volume than the current packages can fit. Nevertheless, some of the orders' dimensions may be higher than the ones of the packages (a product may have less volume than a given package, but one of its dimensions is very high. For instance, a product has a length of 50 cm, but the width and the height are only of 1 cm). So, the process of packaging may be harder. To face this problem, a standardization of the packaging was conducted.

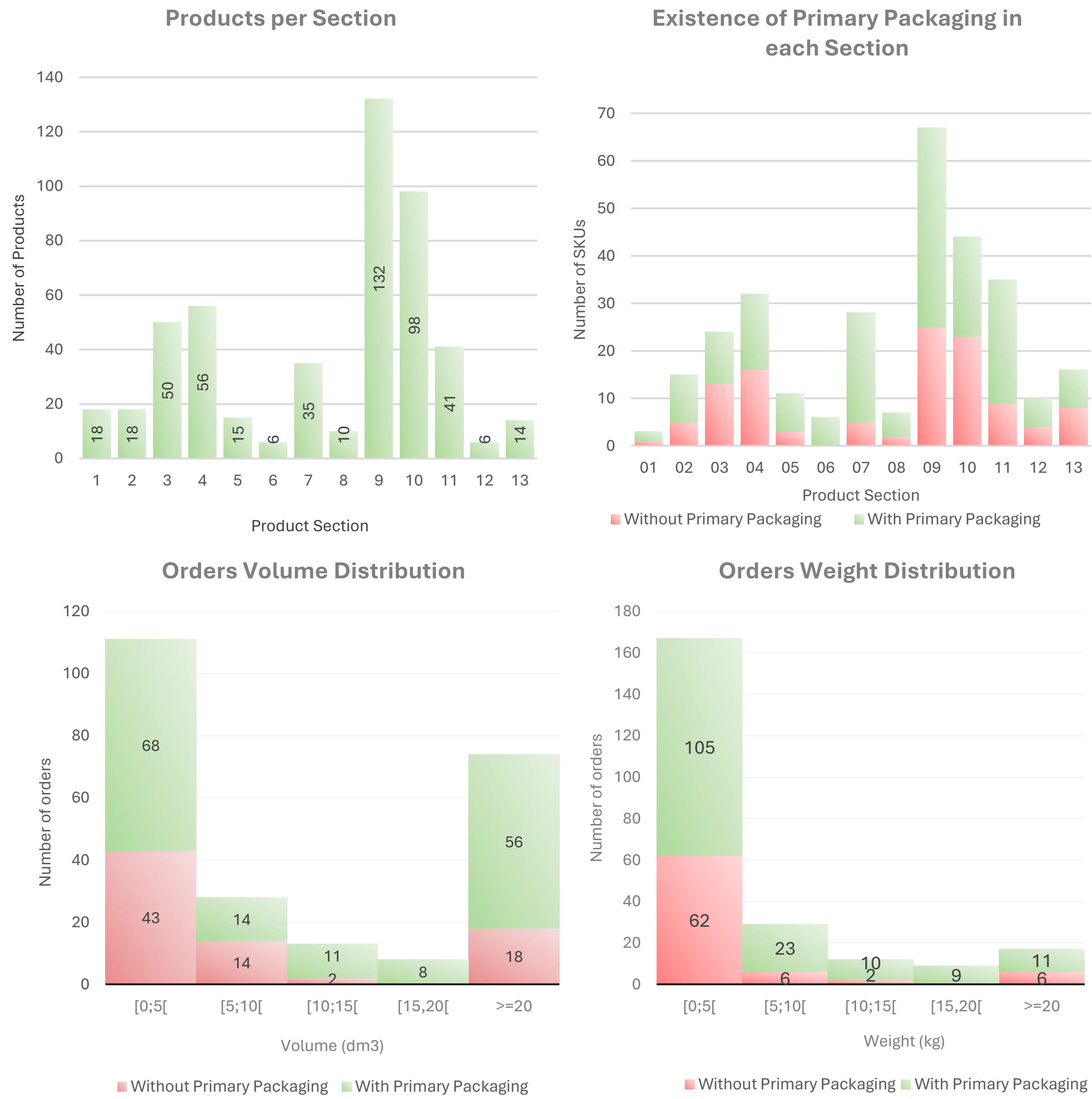


Figure 16*. Porto Alto observations - Orders information.*

5.2. Packaging Standardization

Considering the observations made at the Porto Alto Warehouse, it was noticeable the lack of standardization of processes regarding the packaging of small volumes. With its implementation, greater efficiency is sought in the use of packaging, i.e., a reduction in the materials consumed and the use of larger packaging than is actually necessary. It should also be considered that this standardization was used equally for the manual scenarios presented (Scenario 1, 2 and 3), to allow a fair comparison in the allocation of products. The flowchart in ***Figure 17*** intendeds to illustrate how the process unfolds.

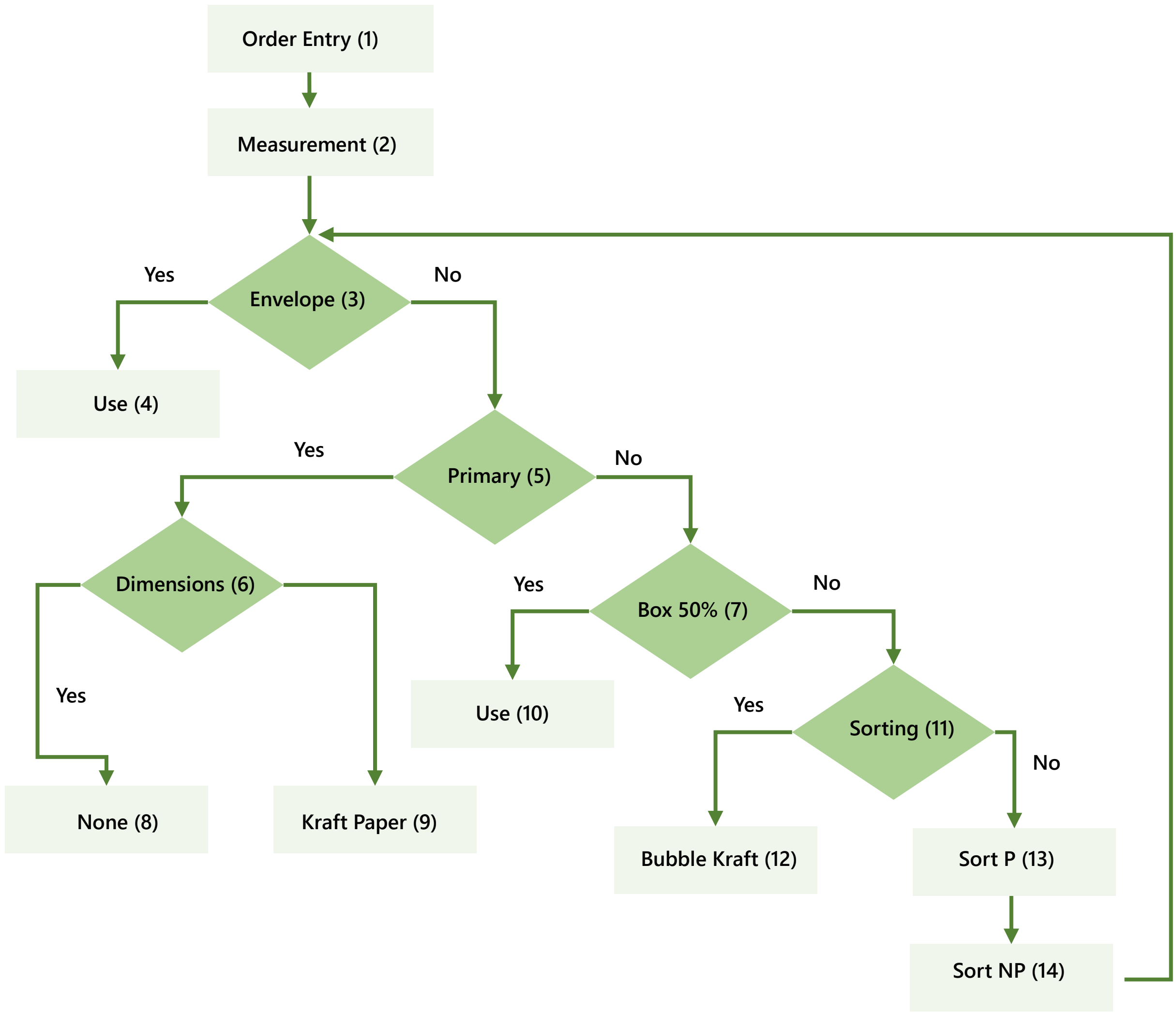


Figure 17. *Packaging Standardization Flowchart.*

Legend:

(1) The order enters in the system.
(2) The products of the order are measured (Weight, Width, Length, Height).
(3) Do all the products of the order fit in an envelope?
(4) Use the smallest envelope possible.
(5) Do all the products of the order have primary packaging?
(6) Do the products have enough dimension to not have a secondary packaging?
(7) Do the products fit in a box and fill at least 50% of the box capacity?
(8) The products do not need a secondary package.
(9) The products are packed with kraft paper.
(10) Use the smallest box possible.
(11) Was the order already sorted in products with and without primary packaging?
(12) The products are packed with bubble kraft.
(13) Sort the products with primary packaging.
(14) Sort the products without primary packaging.

Standardization Example:

For instance, consider an order composed by a vase, without primary packaging and with dimensions of 20 cm,10 cm and 10 cm; and a paint with primary packaging and dimensions of 30 cm,15 cm and 10 cm. The first step would be assessing the total order dimensions, which would be 30 cm,25 cm and 20 cm. Considering the envelopes proposed, the order could not fit either in current or compostable envelopes, since the smallest order dimension (20cm) is higher than any of these envelopes' smaller dimensions. However, this order does fit in a large reusable envelope, so this one would be used. Likewise, for scenario 2, this order would be allocated to that envelope. Then it is determined if all the products of the order have primary packaging. In this case, no. So, there is a need to look at the boxes. The total order volume is 15 dm^3. So, considering only the order volume, it could be allocated to a small single usage box, since the filling rate is over 50% ($15dm^3/18dm^3=83\%$) ,for scenario 1, and to a large reusable box, for scenario 3, where the filling rate is not considered. Then, considering the order and boxes dimensions, it is necessary to look if the product, indeed fits, in a box. For scenario 1, all the orders dimensions are equal or smaller than the box ones, so it could be allocated to a small box. However, for scenario 3 this does not happen, since the smallest measure of a large reusable box, is lower than the smallest order dimension value (20cm >18cm). So, there is a need to divide the order in products with and without primary packaging and do the procedure again. Neither the vase nor the paint , fit in a compostable envelope. Since the vase does not fit in any compostable envelope, it is seen again if does fit in a box. It does fit in a medium reusable box, so the vase can be allocated to this box. The paint does have primary packaging, so there is a need to decide if the product need to be packed or not. The criteria values are available in ***Table 9***. Considering those values, the paint does not need any extra package. ***Figure 18*** represents this example.

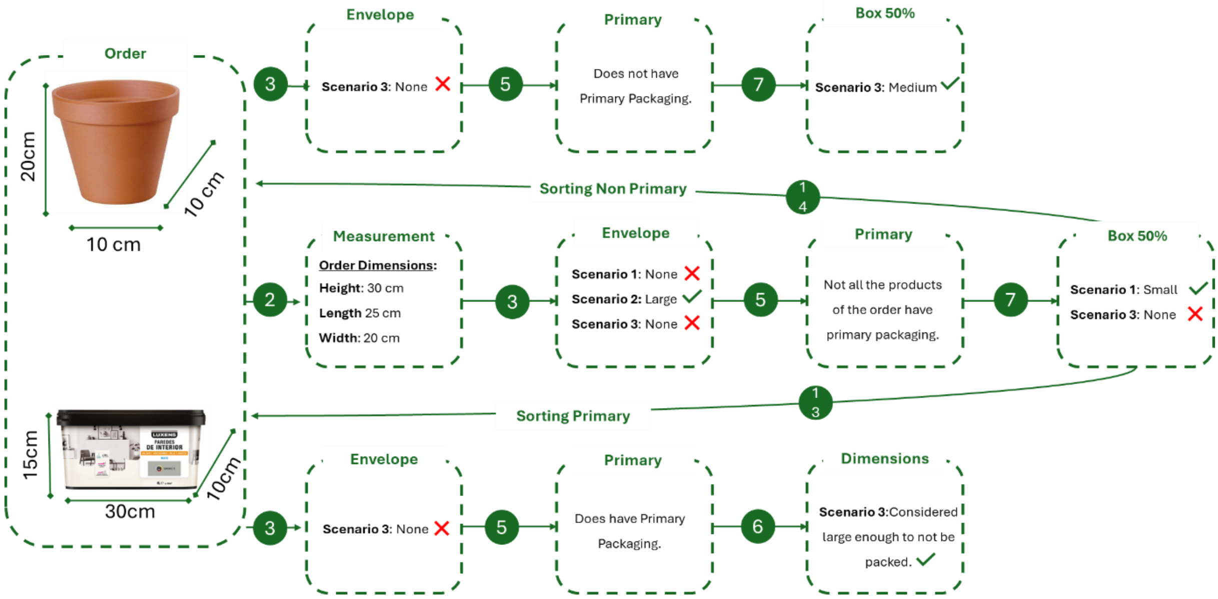


Figure 18. *Standardization Example.*

5.2.1. Definition of Products That Have Primary Packaging

One of the steps in the process of packaging standardization was to distinguish which products have primary packaging, and which do not. This distinction is important to understand which products necessarily need packaging. Products that have primary packaging, i.e., already packaged by suppliers, will be, a priori, protected, not needing another complementary packaging (secondary packaging). Since there was no data on whether or not each product had primary packaging, the code of each product was sought from observations made on the LMPT website. If the product had information about the dimensions of the packaged product, it was considered as having primary packaging. The same happened to all the products, which despite not having dimensions on the website, were liquid products (paints for example). The remaining products were considered as not having primary packaging. In ***Figure 19*** an example of this distinction is presented.

Figure 19. *Distinction between products that have and do not have primary packaging.*

5.2.2. Envelopes and Boxes Usage

To determine when the packages and boxes would be used, it was firstly considered whether or not the products had primary packaging. If the product does not have primary packaging, it will always have to be packed. Envelopes were always considered first, as they are smaller and lighter (considering current packaging, the larger envelope is five times lighter than the small box). With this, it is intended not only to reduce the consumption of materials, but also to ensure that the packaging is filled by products as much as possible. Considering costs, envelopes are also cheaper (assuming they are all of the same nature, i.e., all disposable or all reusable). Except the bigger envelope, which is more expensive than a small box. Considering the green dot value, envelopes also have a lower tax.

The use of boxes was reduced as much as possible, especially considering the consumer's point of view, trying to avoid overpackaging problems, i.e., products placed in overly large packages. In this way, the limitation placed was that the boxes could only be used if their fill rate was at least 50%. This value was chosen because it is easy to identify for an operator, realizing whether the box is half full or not. If necessary, the operator can choose to fill the box with filler material. For standardization purposes and in order to eliminate the operator's choice variable, it was decided to consider that if a disposable box was used, the filling material would not be used. In products that do not have primary packaging and do not fit in any package, external packaging will have to be used.

For products with primary packaging, only the possibility of using envelopes was considered. This is due to the fact that they are lighter than boxes, leading to a lower consumption of materials. If products are larger than an envelope, they are considered large enough not to be packaged. For situations in which an order has several products with primary packaging, with dimensions smaller than an envelope, but the set of all products does not fit inside an envelope, the use of external packaging was considered in order to allow the consolidation of these smaller products. For orders where there are products with and without primary packaging, it was tried to ensure that they all fit inside an envelope first and, if this does not work, the products with no primary packaging are separated. It is again tested whether products without primary packaging fit inside an envelope. If not, external packaging will be used. For products with primary packaging, the procedure will be the same as previously described for this type of product.

5.2.3. External Conditioning Usage

The use of external packaging is related with the inexistence of primary packaging and the dimensions of the product. In addition, the use of this type of packaging is conditioned to products that do not fit inside an envelope or box. Considering this, if the product has primary packaging, and at least two dimensions are equal or greater than 20 cm, it does not need any packaging, as it is considered large enough to be easily visible by the operators who carry out the delivery process being properly packaged. This dimension was chosen considering the average dimensions of the sample observed. The second largest dimension of a product is, on average, 25 cm. In order to be conservative in the analysis, a 20% reduction was made in this value. The same would be considered for products whose largest dimension is equal to or greater than 1m. In this way, products with a large disparity between dimensions (length, width, and height) were covered. For products that did not require packaging were also considered those with the smallest dimension equal to or greater than 10 cm, given that the largest dimension was equal to or greater than 20 cm.

For the remaining products with primary packaging, kraft paper was used to provide extra protection for products with smaller dimensions. In addition, from the observations made, it is noticeable that this behaviour turns out to be already adopted by operators for most products that are within these characteristics. However, these dimensions will always be merely indicative, ultimately it will always be necessary to evaluate the product and understand whether or not it needs external packaging. In order to be able to compare scenarios, this solution was adopted, and in the analysis of results, the boundary between using or not using will be manipulated to understand the impact of using more or less external packaging.

Products that do not have primary packaging will always have to be packaged. If they do not fit in any of the proposed packages, the products will be packed with kraft bubble in order to be protected. ***Table 9*** summarizes how the external packaging is allocated.

Table 9. *Allocation of external packaging.*

Does it have Primary Packaging?	Criteria	Package Used
No	- Does not fit in an envelope. - Does not occupy at least 50% of a box.	Kraft Bubble
Yes	- Does not fit in an envelope. - At least one dimension equal or bigger than 1 m. - At least two dimensions equal or bigger than 20 cm. - All dimensions bigger equal or bigger than 10 cm and at least one equal or bigger than 20 cm.	None
Yes	- Does not fit in an envelope. - At least two dimensions are smaller than 20 cm. - None of the dimensions is over 1m.	Kraft Paper

5.3. Baseline Results

This section presents results from the baseline packaging configuration, based on the observations made at the Porto Alto Warehouse. ***Figure 20*** illustrates the current packaging allocation for each order, and how many orders that have, or not, primary packaging, in each available package. Note that one order may have more than one package used (for example, an envelope and a box may be used in the same order). So, the sum of all packages used is more than the orders considered. The external packaging materials include bubble wrap, corrugated cardboard, and stretch film, which were all considered in the same category for simplification purposes (external packaging). The proposed standardization process is not applied in this configuration, instead, current packaging practices, where each operator follows their own method, are considered.

The prevalence of small boxes and medium envelopes as the most commonly used packages aligns with the average order dimensions (see ***Figure 16***) since the majority of the orders have a total volume of less than 5 dm^3 and these packages can fit volumes in this range. However, considering only this value, small boxes would be barely used, so this may be an early indicator of inefficient packaging allocation. Small boxes would have a higher filling rate for orders that range between the 10 dm^3 and 15 dm^3. If this happened, the maximum number of small boxes used would be 13, which corresponds to the number of orders that lay in this volume range. To add to this reasoning, the use of filling paper may be another signal of an inefficient allocation. Consequently, filling paper is employed in 39 orders with products already having primary packaging, so its usage could be avoided in these orders. However, some orders have the combination of products with and without primary packaging, so in these situations the use of filling paper is reasonable. Although, this only happens in four orders.

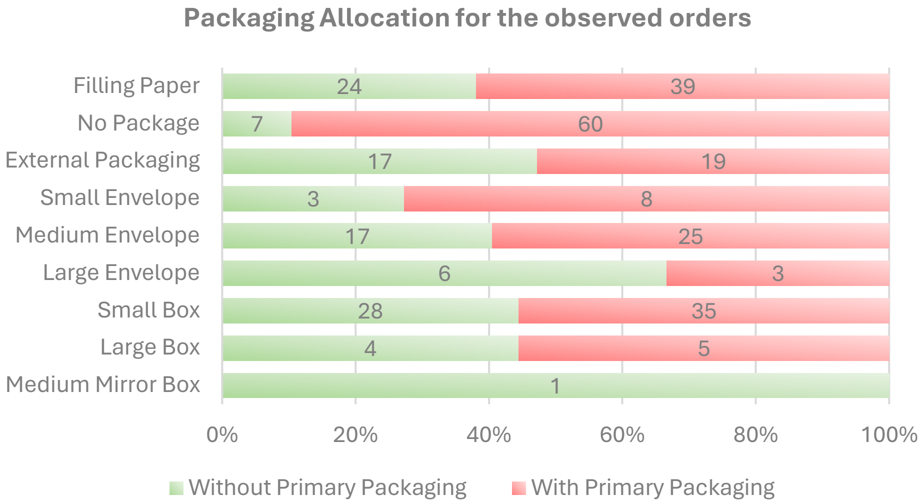


Figure 20. *Packages allocation according to the type of packaging in each order.*

It is relevant to consider each product section of LMPT to understand if the allocation of packages is related with some section or if there is any section responsible for the use of a specific package, since the majority of orders only have one SKU. The allocation of packages for each section is presented in ***Figure 21***.

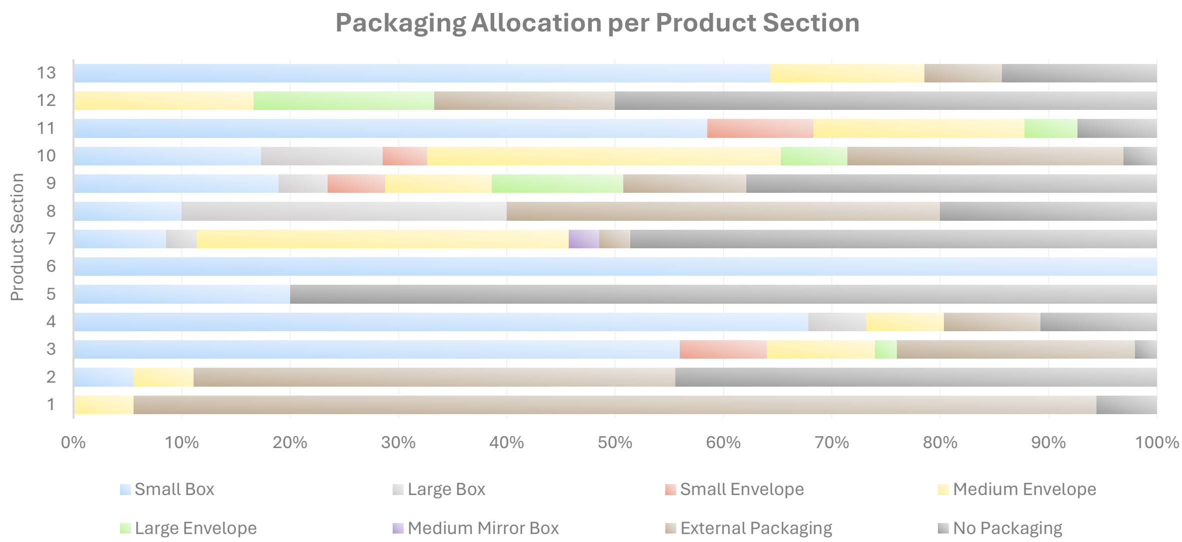


Figure 21. *Packages allocation according to the products section.*

The packaging approach for each product section is distinct. Notably, there is a predominant usage of small boxes across most product sections in the current packaging configuration. For example, in Section 6 (ceramics), exclusively small boxes are employed. This is attributed to the fact that all products within this section are associated with only one order and correspond to a single SKU. Therefore, making judgements on the packages allocation in this section will not lead to precise conclusions, since the sample is very small. In contrast, in section 1 (construction materials), boxes are not used, being the external packaging the most used. This can be attributed to the nature of section 1, which pertains to construction materials, where only three SKUs are represented and two of them have primary packaging. It is important to underscore that these SKUs correspond to three different orders, and the higher value of external packaging is given to the fact that the number of units is higher in the order that used this packaging type (16 units while in the other orders only one product of the remaining SKUs was contemplated). So, in this section, the reasoning for the packaging allocation seems to be correct: Products that have primary package are not packed, while the ones that do not have, are packed. But there is a need to verify if the package allocation for the SKUs without primary packaging is the most efficient.

It would be expected that the no usage of packaging would be bigger in sections where the majority of the products have primary packaging (section 3 - comfort). However, no packaging only happens in 2% of the products. Although, this decision is always dependent on the dimensions of the products: It would not make sense to not pack a product considered to be small, even though it has a primary package. But, given the fact that in this section, about 55% of the products are packed in a small box, it is expected that some of them are considered to be big enough to not be packed. To note also that section 12 (decoration) is the only one that do not have any small boxes applied. This may be an indication that the majority of the SKUs in this section either have small volumes (< 5dm^3) or larger volumes (> 20 dm^3), corresponding to the first and last bins, as seen in ***Figure 16***. To better understand how efficient the packages are being used, it is useful to calculate the filling rates for each package, as shown in ***Figure 22.***

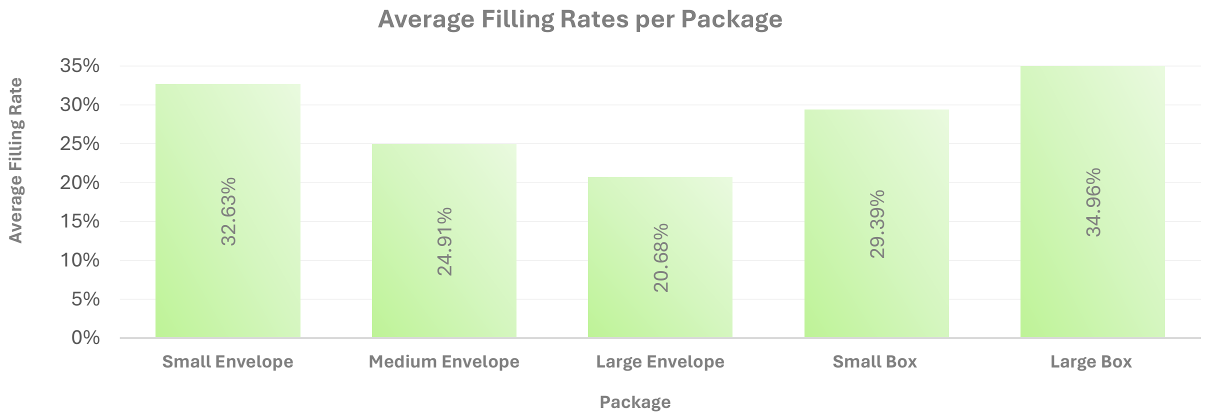


Figure 22*. Average filling Rates per package.*

The analysis of package utilization reveals that none of the packages exhibits a filling rate exceeding 35%. These low filling rates suggest potential issues with product allocation to the correct packages, or a need of a re-evaluation on the package dimensions used. Regarding envelopes, there is an inverse relationship between volume and filling rate, i.e., the higher the volume that an envelope can fit, the lower the filling rate is, indicating that certain SKUs assigned to medium or larger envelopes could be accommodated into smaller envelopes. However, some products possess small volumes but may have dimensions (length, width, or height) that prevent them from fitting into the most efficient envelope size.

For boxes, the opposite occurs. As seen in ***Figure 20*** small boxes are the most common package used, so it is reasonable to assume that many products allocated to small boxes could potentially be assigned to envelopes, given the low filling rates observed. Looking at the volume distribution of orders (***Figure 16***), a large envelope could, theoretically, fit about 55% of the orders, and the medium envelope 49% of the orders, being the small envelope reserved for the SKUs with less than $2dm^3$. In terms of boxes, if a standard practice in packaging operations were to allocate products with volumes exceeding 10 dm^3 to boxes, the filling rate for small boxes should ideally be at least 55% (by dividing the volume of the order and small box), and for larger boxes, at least 28%. To gain further insights into how orders volume and weight impact filling rates, an analysis of filling rates within volume and weight intervals was conducted, as illustrated in **Figure 23**.

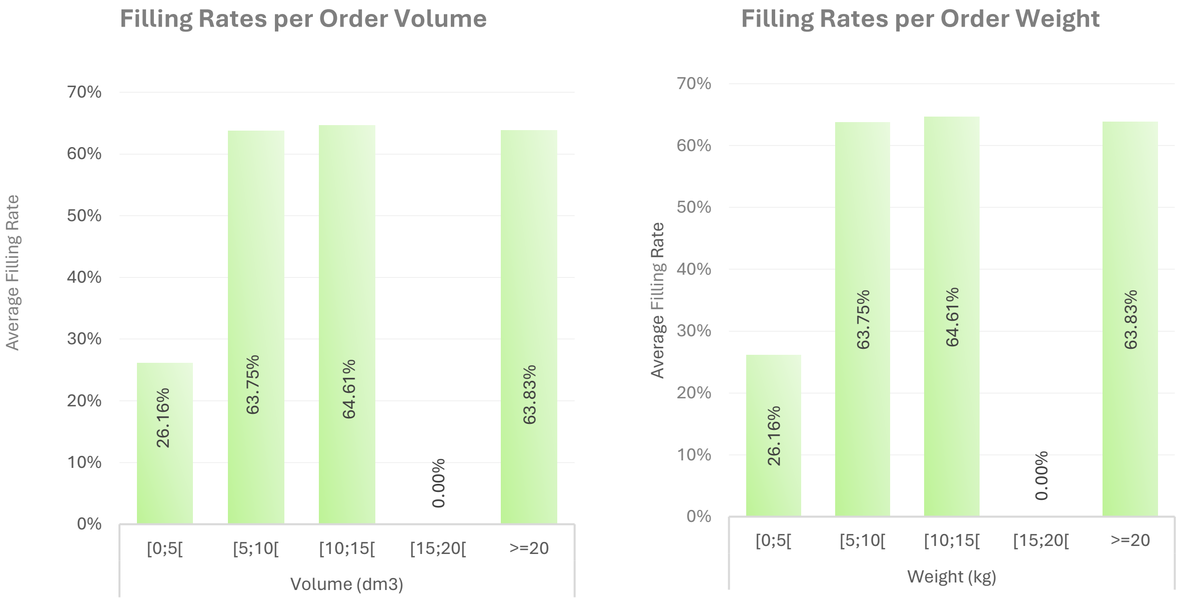


Figure 23. Average Filling Rates per Order Volume and Weight.

The similarity in filling rates between weight and volume intervals suggests that all packaged orders fall within the same weight and volume ranges (***Figure 16***), i.e., an order packed is in the bin of 0 to 5kg and 0 to 5 dm^3. This indicates that the remaining orders that do not fit this property do not have any packaging. This primarily pertains to low-density orders characterized by volumes exceeding 20 dm^3 and weights below 5 kg.

Considering the total volume, it is seen that there is a higher inefficiency of packaging allocation in orders with smaller volumes and weights. This is a problematic since it lays in the majority of the orders considered and reinforces the idea of a possible wrong allocation of products or a necessity of rethinking the packages dimensions. For the orders with a volume higher than 5 dm^3, the performance is similar. However, in the bin that ranges from $15dm^3$ to $20dm^3$ the filling rate is 0% which is indicative that orders within this range of value do not have any extra packaging. So, the idea of using small or large boxes in this range was not considered by the operators.

To comprehend how packages are allocated to each order volume interval, ***Figure 24*** presents its allocation.

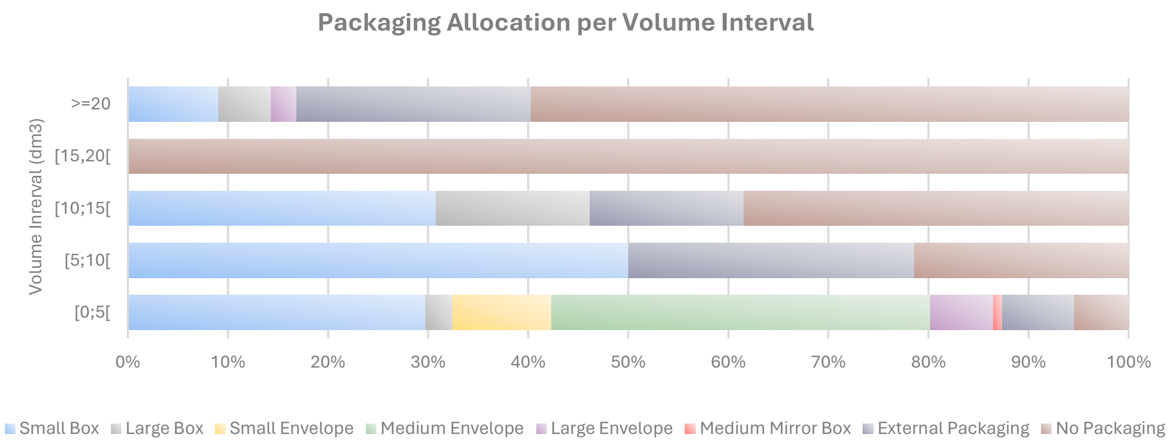


Figure 24*. Packaging allocation per order volume interval.*

With the allocation of packages given on ***Figure 24***, it is visible a gradual increment in the combination of no packaging usage and external packaging, from smaller to larger order volumes. This is expected since the current packages will not be large enough to contain the products of a given order. Envelopes are only used for orders that have at most 5 dm^3. The exception is larger envelopes, which are also present for orders that have a volume larger than 20 dm^3. However, this is not feasible, since the volume of a large envelope is lower than 20 dm^3, so this indicates that either occurred an error in registration by operators, wrong information in LMPT website or a wrong approximation was made, as explained in **Section 4.2.** The same reasoning happens for small boxes, which also have a capacity smaller than 20 dm^3.

The use of external packaging is also higher for orders with larger volumes, as expected. In the interval from 15 to 20 dm^3 it is possible to understand that no package was used, which then allows to explain the reasoning that, for a given dimension, and considering that the product have primary package, the operators do not add any extra package. So, considering this decision made intuitively by the operators, it is then relevant to see how it translates in materials consumptions. ***Figure 25*** presents how much weight for each package was consumed.

The results obtained indicate that the predominant weight contributions come from either small boxes or filling material, which aligns with their high usage rates. The substantial contribution of filling paper to the overall weight suggests that the current allocation of packages lacks efficiency. With an optimized allocation, this value could potentially be reduced, or even eliminated entirely, especially when fragile products are not considered, given that the main objective of filling paper is to protect the product. Furthermore, all packaging materials related to boxes (small box, filling paper, and large box) account for 87.5% of the total material consumption, while envelopes have a comparatively lower impact on material usage.

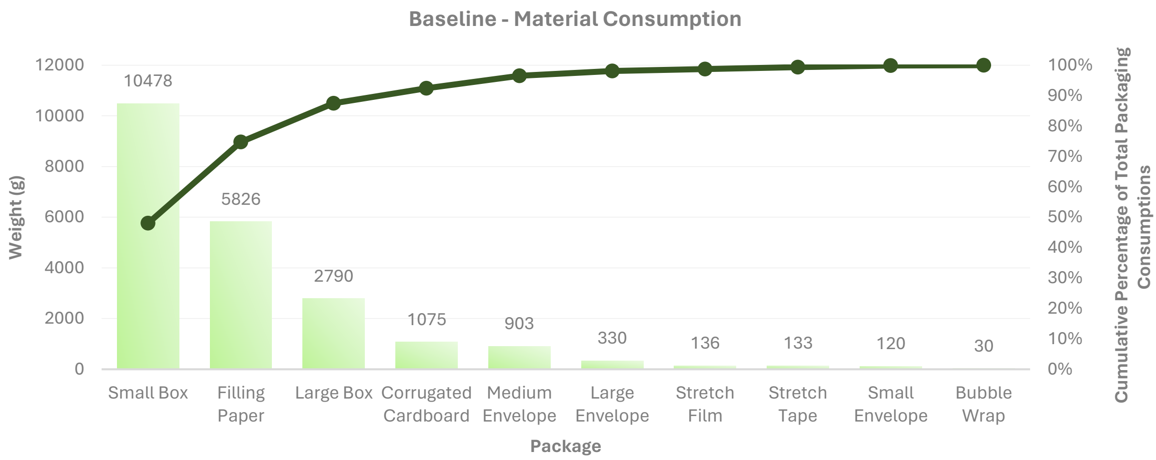


Figure 25. *Materials Consumption in Baseline Packaging Configuration*

Figure 20 indicates the use of 71 boxes and 63 envelopes. Given that boxes are heavier than envelopes, the low filling rates for boxes have a more pronounced impact compared to the envelopes, which exhibit even lower filling rates, as presented in ***Figure 22***. The substantial difference in material consumption between boxes and envelopes (14.11 times more material used in boxes), indicates the greater significance of boxes in the current packaging configuration when compared to envelopes. Thus, external packaging materials contribute minimally to the overall material consumption, with the majority of their weight being attributed to corrugated cardboard.

Despite corrugated cardboard and stretch film being used the same number of times, corrugated cardboard's weight is 7.9 times higher. However, corrugated cardboard offers superior protective properties compared to stretch film, which should factor into the packaging process. Additionally, it is worth noting that both materials can be utilized in the same order. Considering that the reduction of packaging costs is one of this dissertation objectives, it is relevant to compare them and relate with the consumptions obtained. To do so, ***Figure 26*** shows how packaging costs are distributed per package.

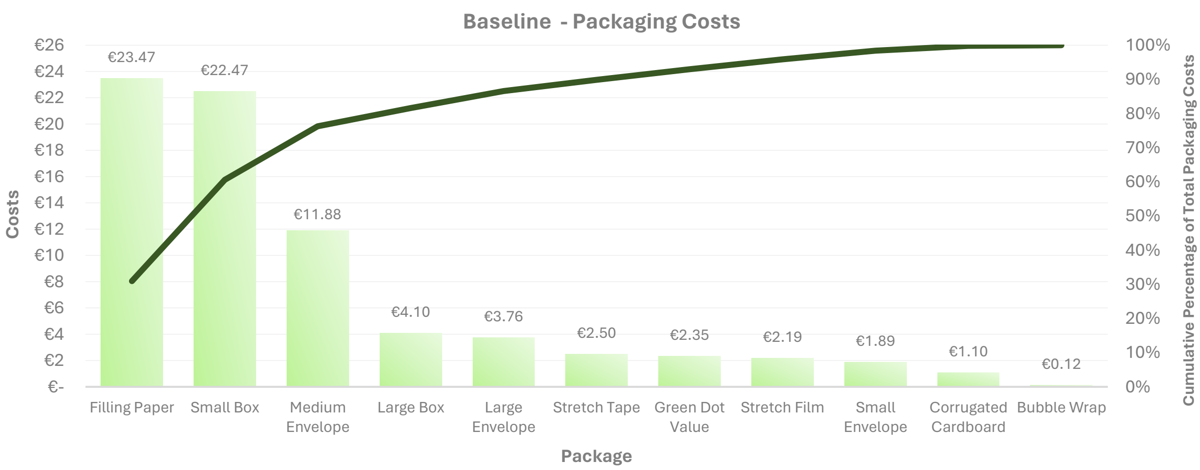


Figure 26. *Packaging Costs in Baseline Packaging Configuration.*

Considering costs, filling paper is the option with the highest weight in packaging costs. Small boxes come in a close second regarding costs, as being the most used package, it would be expected to be the most expensive. Medium envelopes end up has being more expensive than large boxes, although the latter consumes more material. The proportion between these two options is similar regarding costs and materials consumption: the medium envelopes are 2.90 times more costly in this packaging configuration, but large boxes consume 3.09 more materials. However, to note that large boxes, are twice as expensive than medium envelopes (per unit) and medium envelopes are used 4.66 more than boxes, so the value is expected. A similar cost-effectiveness trade-off is observed between stretch film and corrugated cardboard, with the latter being the more economical choice for the same usage.

From the green dot value which consider plastics and paper consumption (as explained in **subsection 4.4.7**), it is noteworthy that the majority of the consumption comes from paper (consult ***Table 12***) . This is primarily due to the fact that 60% of packaging consumption is associated with boxes, which are predominantly made from cardboard. Since paper has a lower price per kg compared to plastics, it emerges as the most cost-effective option when aiming to minimize this value within a packaging configuration. Comparing the external packaging options, it is more cost-effective to use paper instead of plastic (corrugated cardboard vs. stretch film). Although bubble wrap, which serves as an equivalent to corrugated cardboard, has a limited sample size and was used only once, the higher price per kg of bubble wrap supports the same reasoning.

The different environmental impact categories for the baseline configuration and how much each package affects these 18 categories are represented in ***Figure 27*.**

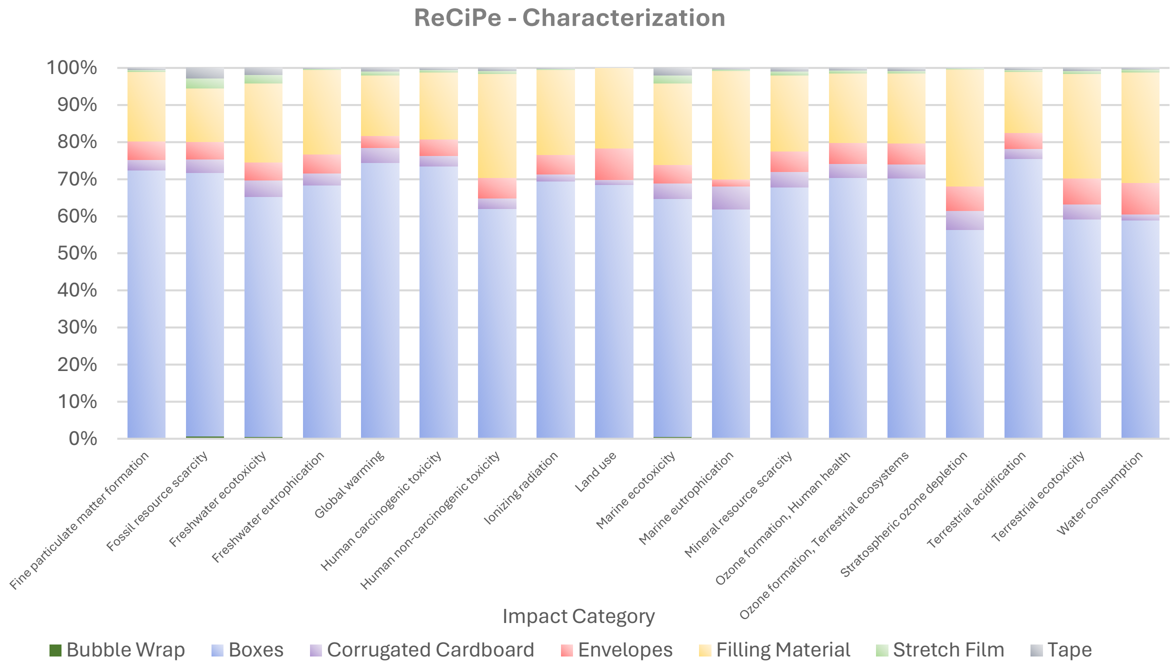


Figure 27. *ReCiPe Characterization - Baseline Configuration*

In line with the results obtained in materials consumption, boxes are the ones who contribute more to the result of each impact category. Indeed, in all categories, at least 50% of the contribution comes from boxes. This is expected since boxes correspond to 60% of total material consumptions. However, the boxes average contribution in each category is below that.

Filling Materials comes second in contribution of all categories, going in line with the reasoning made for boxes. The contribution of filling materials ranges from 18% to 33% considering the 18 impact categories. Envelopes are then the third most impactful component in all but one (Global warming) category, which is one of the main focuses of LMPT. In this category, the usage of corrugated cardboard over envelopes has more impacts.

The contribution of each package to the single score of the baseline configuration is shown in ***Figure 28***.

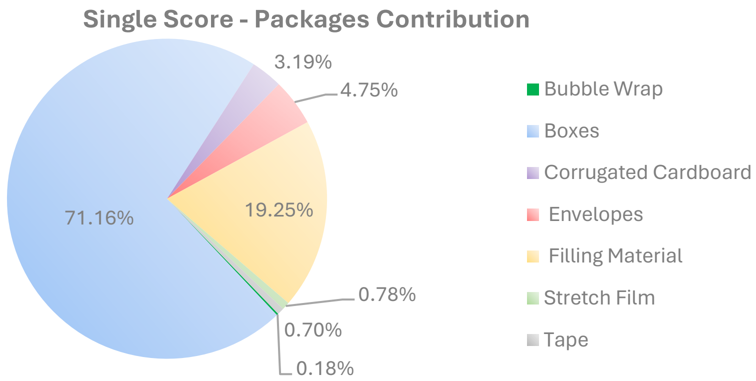


Figure 28. *Single Score of Baseline Configuration*

Figure 28 illustrates that boxes are the packaging option with the highest contribution to environmental impacts, followed by filling materials and envelopes. This aligns with the reasoning discussed regarding the impact categories, being the single score largely attributed to the substantial material consumption associated with boxes. However, while boxes consume approximately twice the weight of filling material, this proportion does not directly translate to environmental impacts. In fact, boxes are 3.7 times more environmentally impactful than filling paper. This disparity underlines that the environmental impact is not solely determined by material weight but also depends on other factors such as the type of material, production processes, energy usage, and transportation, which were included in the modelling as indicated in **Section 4.5.**

5.4. Comparation with the Scenarios Proposed

In this section, a comparison between the results of the baseline scenario and the scenarios proposed is presented. It is made a comparation between the overall packages filling rates across the scenarios, order volumes and packages used. Then, the material consumption and packaging costs are compared between scenarios, following the reasoning presented for the baseline scenario. To conclude, the environmental impacts are compared, allowing to distinguish between scenarios which has the lowest overall environmental impact.

Table 10 presents the packaging usages in each scenario while ***Figure 29*** shows the distribution of packages filling rates across the different scenarios. Four different packages filling intervals are represented, allowing to see how the filling values fluctuate across the scenarios. In these filling values, the usage of external packaging is included.

Table 10. *Packaging allocation for each scenario.*

Package	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Envelopes	62	59	125	59	-
Boxes	73	2	0	4	160
External Packaging	45	74	35	72	-
Filling Paper	72	-	-	-	-

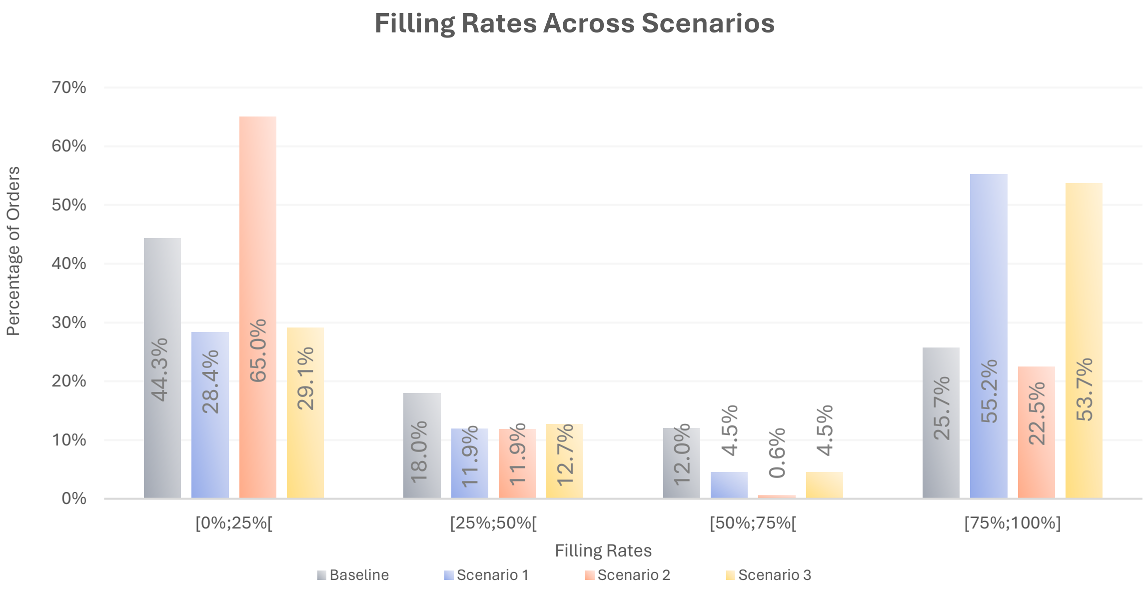


Figure 29. *Distribution of filling rates across scenarios.*

Comparing with the baseline packaging configuration, scenarios 1 and 3 have an overall higher average filling rate. In both scenarios, over 50% of the orders have a filling rate of at least 75%. This is highly influenced due to an increase of external packaging usage **(*Table 10*)**. This range of filling values (75% to 100%) encompasses all the orders that were packed in this manner. The obligation of a minimal 50% box filling rate in scenario 1 justifies the 1.5 percentual points differential between scenarios 1 and 3 in this range. Scenario 1 includes orders that could fit in a box, but since they had a filling rate of less than 50%, the external packages were used, which corresponds to two more orders packed by using external packaging in scenario 1 when compared to the scenario 3. In fact, boxes filling rates in scenario 1 are all comprised in the 50 to 75% interval. To note that the reusable boxes used in scenario 3 have less capacity. Thus, since that the constraint of having at least 50% of its capacity occupied was not imposed, half of the orders that were packed in a reusable box have less than 50% of its filling capacity. The other half has between 50 and 75%. The envelopes used in both scenarios are the same, so the filling rates regarding these two scenarios won't suffer changes in this packaging type, being the change within the scenarios verified in the boxes' allocation only.

Scenario 2 has the lower filling rate values. This is expected considering the way that the packaging standardization process was conducted. By prioritizing the usage of envelopes, and since scenario 2 has the envelopes with higher dimensions, by not imposing any constraints regarding envelopes minimal filling, there will be a lot of orders allocated to envelopes. So, the lower filling values in scenario 2 can be explained due to high volume envelopes: The values over 50% are either, rare cases where the envelope is used over 50% (only 0.6% of the orders), or orders where external package was used. Boxes were not used since reusable boxes are smaller than reusable envelopes.

Table 11 presents the average filling rates in each scenario. To consider that scenario 4 was not considered in ***Figure 29*** since the filling rate is 100%.

Table 11. *Scenarios average filling rates and total empty space*

Scenario	Average Filling Rate
Baseline	55.05%
Scenario 1	65.90%
Scenario 2	32.20%
Scenario 3	64.66%
Scenario 4	100.00%

After looking at the overall values, to comprehend how they are distributed, ***Figure 30*** shows the filling rates distribution regarding orders volume ranges.

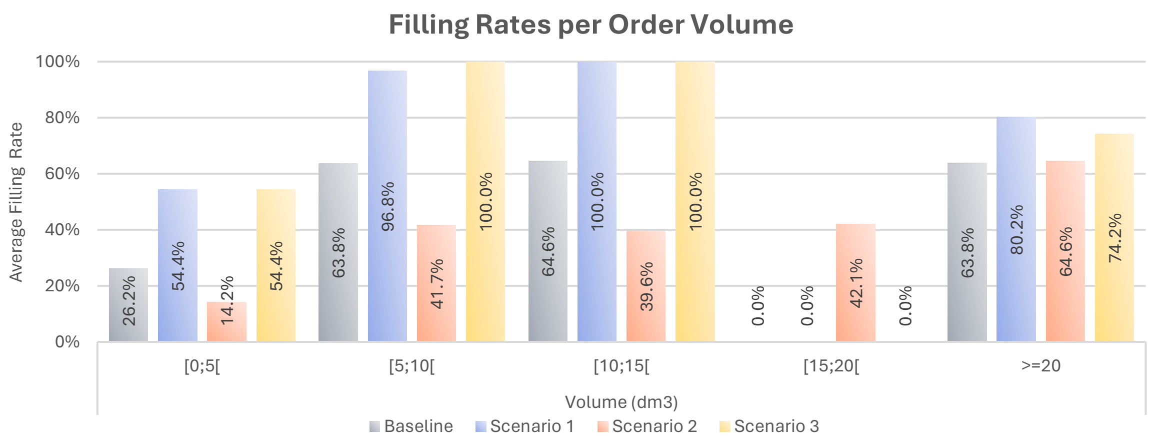


Figure 30. *Average filling rates in each volume interval across scenarios.*

Comparing with the baseline configuration, scenarios 1 and 3 have higher packaging filling values in all intervals. A value of 100% is indicative that all orders laying in that volume range were packed by using external packaging, since none of the boxes or envelopes can reach this value. In these two scenarios, the average filling rate duplicates in the first interval of volumes (0 to 5 dm^3) when compared with baseline configuration. So, the main differences regarding overall average filling rates lay in the better allocation of packages for the smaller volumes. The opposite reasoning can be performed for scenario

2. A 12 percentual points difference in the orders that range from 0 to 5dm^3 between the baseline configuration and scenario 2 represents the major influence for the overall filling rate difference (***Table 11***). This scenario has the lower values for all order volumes, with the exception for orders with a volume over 20 dm^3. Although this is the second most representative interval, the difference between scenarios is less than 1 percental point, so it will not make major differences in the overall values. In the 15 to 20 dm^3 interval, the scenario 2 is the only scenario where any packaging is used, while the other scenarios do not have any order with packed.

After looking at volumes' intervals, it is relevant to analyse how efficiently packages are allocated when compared with the baseline configuration. ***Figure 31*** shows how packages are allocated across scenarios and its average filling rate.

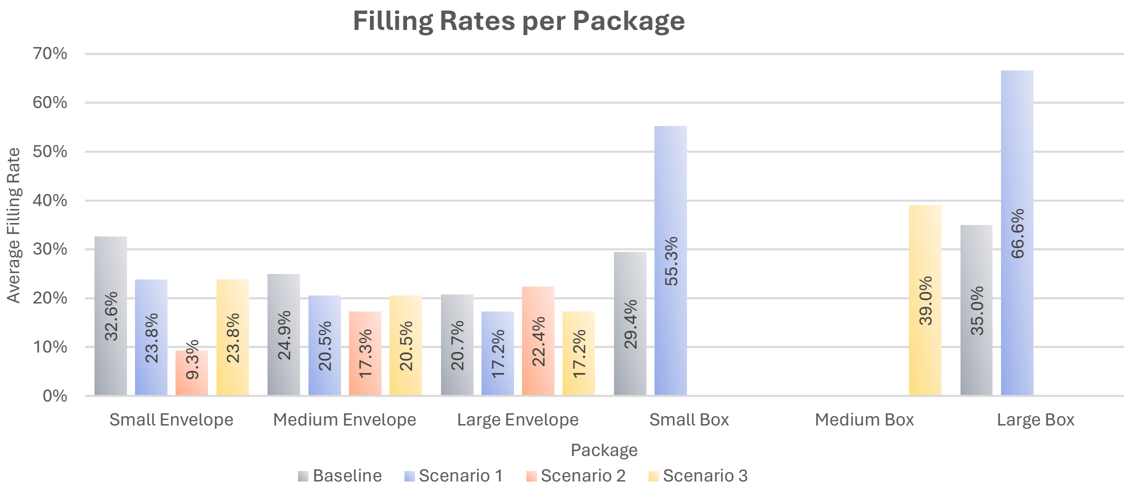


Figure 31. *Average filling rates per package across scenarios.*

Analysing the different packages allocation, it is seen that the proposed scenarios have lower values in the envelope's usage but higher in boxes. This is expected accordingly to the trade-off that was considered in the standardization process, where the use of envelopes was prioritized, and the boxes uses was reserved for orders with higher volumes. Accordingly, scenario 1 will always have values over 50% in boxes average filling rate, as it is confirmed by the results in ***Figure 31***. That does not occur in scenario 3, since there was no minimum filling rate constraint, but the values are still higher than the ones on baseline configuration, benefiting for the smaller dimensions of reusable boxes.

For envelopes, in scenarios 1 and 3 the values are lower when compared with the baseline configuration since the compostable envelopes are slightly larger than the ones currently used in LMPT online packaging operations. The same reasoning can be performed for scenario 2: The value of 9.3% for the small envelope is explained considering that it is excessively large for the smaller units, encompassing a lot of orders. In fact, the small reusable envelope is larger than the large envelope used in the baseline configuration, helping to explain the low value obtained. The large reusable envelope is larger than the large box used in current operations. So, this envelope includes also orders that were allocated to boxes in the baseline configuration, explaining that the value is higher than the remaining large envelopes, but still lower than the values obtained for smaller boxes in the baseline configurations.

A higher filling rate would mean a better efficiency in packaging allocation, being expected that the materials consumption would be lower. ***Figure 32*** shows how consumptions are distributed across the four proposed scenarios.

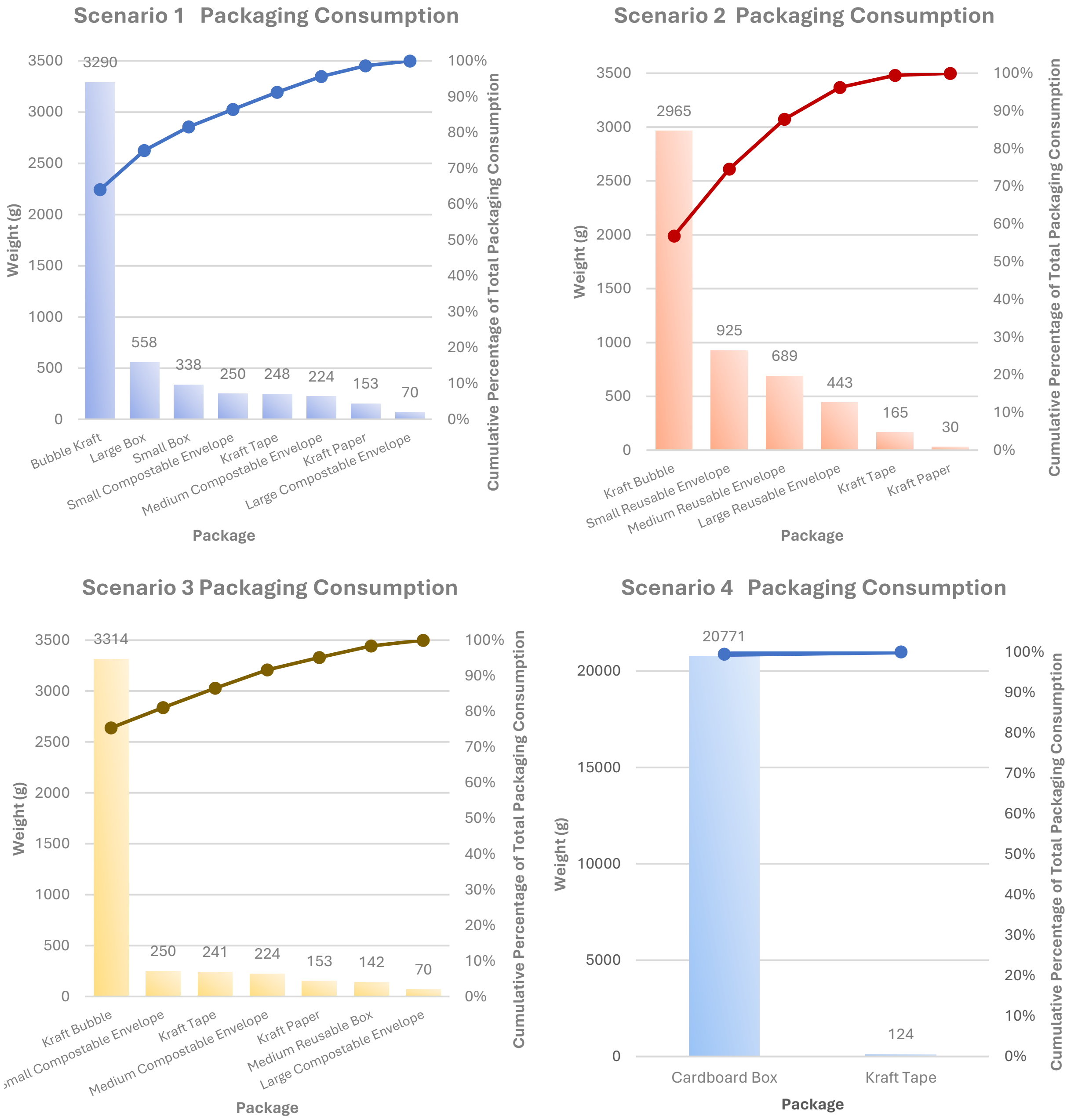


Figure 32. *Packaging consumption across scenarios.*

The packaging consumptions contribution in scenarios 1 and 3 are similar, and the small differences are, as referred before, in the box's allocation. In both scenarios, most of the package's consumption is related with the external packaging (over 60%), being kraft bubble the most used option. This means that a high percentage of products that do not have primary packaging, did not match the criteria on the standardization process, so it was necessary to use this packaging option. In these scenarios, envelopes, despite being used in similar quantities when compared to the boxes in the baseline configuration (***Table 10***), they produce less weight, since each envelope is much lighter than any box.

Thus, in scenario 3, since boxes are reusable, the higher usage of boxes ends up in producing less consumptions.

Scenario 4 consumption is only composed by cardboard and kraft tape, being the first responsible for 99% of the total consumptions while kraft tape is only used to seal up the boxes. In Scenario 2 the most consumed package is kraft bubble, despite envelopes being the most used package. This is expected due to the reusable nature of the envelopes in this scenarios, so more packaging usages do not necessarily mean higher consumptions.

In ***Table 12***, it is presented the division regarding the packaging's material and total packaging weights. The consumption of materials will be reflected in packaging costs, as presented in ***Figure 33*** and **Table 13.**

***Table 12**. Packaging Materials for each scenario.*

Material	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Plastic	540 g	381 g	2 056 g	523 g	0 g
Paper	21 251 g	4 587 g	3 160 g	3 709 g	20 894 g
Compostable	0 g	163 g	0 g	163 g	0 g
TOTAL	21 790 g	5 132 g	5 216 g	4 396 g	20 894 g

Considering the packaging costs obtained in scenarios 1 and 3, kraft bubble, small and medium compostable envelopes correspond to approximately 80% of the packaging costs. This goes in line with what was observed in ***Figure 32***. However, kraft bubble is beneficial regarding the packaging costs, since it represents a reduction in its contribution, respectively for scenarios 1 and 3: 64% and 75% of packaging consumptions but 54% and 53% of packaging costs.

For scenario 2, the same happens. Kraft bubble, small and medium envelopes correspond to approximately 90 % of the packaging costs. However, the absolute values are higher since the unitary cost of a reusable envelope, on average, is about 13 times more expensive than the current envelopes. But considering the reusable and return rates, this value is softened, since the value is amortized for each usage. However, the reuse and return rates are still not enough to make scenario 2 the cheapest option. Instead, Scenario 4 is the one with lower costs, despite being the one with higher material consumption. So, a trade off exists here, the cheapest option corresponds to the one who produces the most material consumption. In scenarios 1,2 and 3, the external packaging is highly represented by kraft bubble, being an indicator that a lot of orders with non-primary packaging are not allocated to either boxes or envelopes.

Considering the four scenarios**, *Figure 34*** shows how packages affects each ReCiPe impact category and their contribution for the single score. The values obtained in the SimaPro software are available in **A.5.2.** Again, scenarios 1 and 3 have a similar performance. In all but one impact category, kraft paper/kraft bubble have the bigger impact. These two packages were joined together since the way both were modelled in the SimaPro software was the same. Thus, being the most impactful in most impact categories is expected, since they are the most used packages and the ones who consume more material, as presented in ***Figure 32***. The exception is in the category stratospheric ozone depletion.

However, when the values are normalized this is the second less impactful category overall. So, this difference between characterized values is not significant.

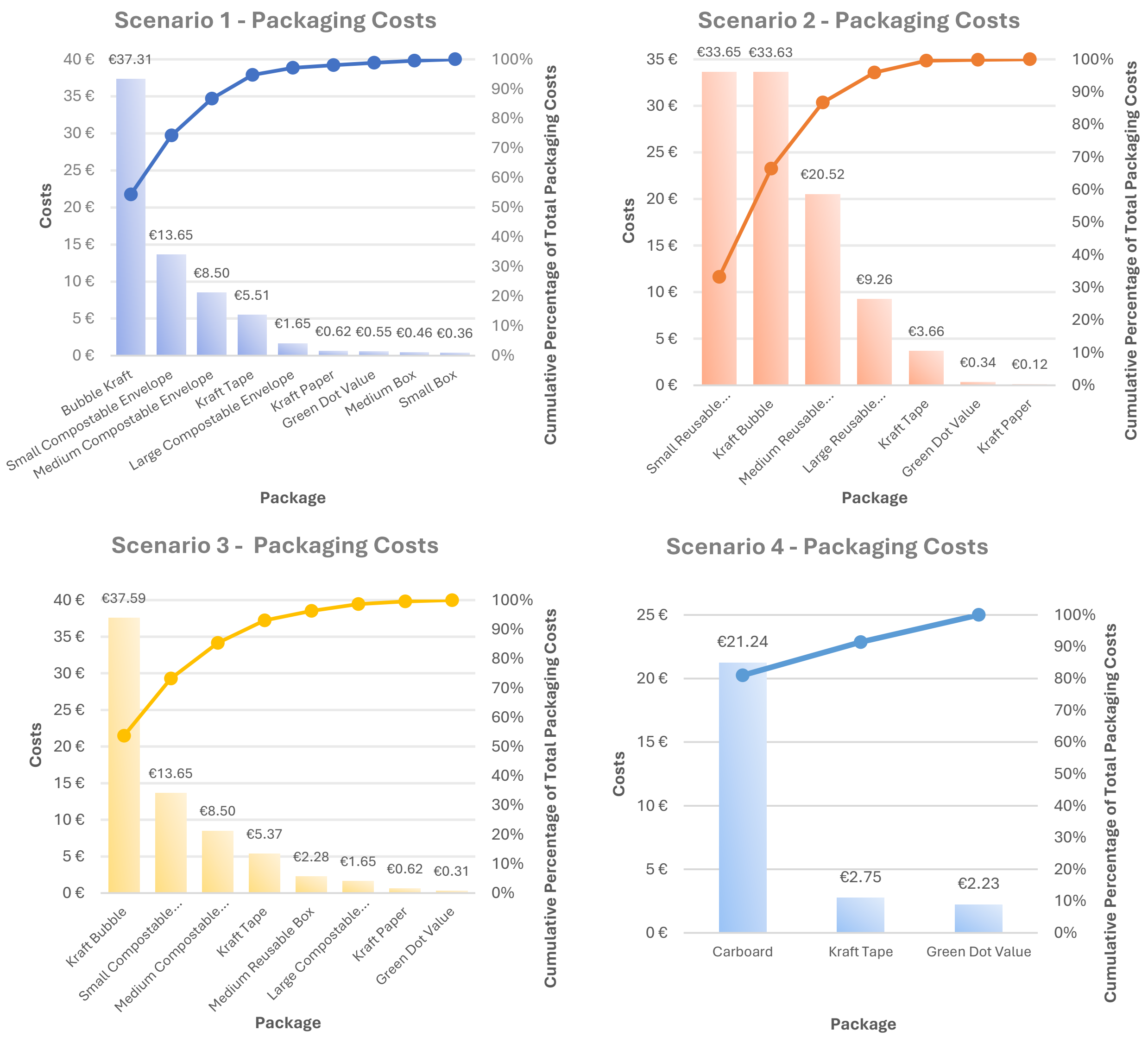


Figure 33. *Packaging costs across scenarios.*

Table 13. *Packaging Materials Costs division for each scenario.*

Material/Tax	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Plastic	8.32 €	16.66 €	63.43 €	18.94 €	0.00€
Paper	65.17 €	44.26 €	37.41 €	43.58 €	23.99 €
Compostable	0.00 €	7.14 €	0.00 €	7.14 €	0.00 €
Green Dot Value	2.35 €	0.55 €	0.34 €	0.31 €	2.23 €
TOTAL	75.85 €	68.61 €	101.18 €	69.97 €	26.22 €

In scenario 2, envelopes are more impactful in 12 of the 18 impact categories despite envelopes not being the most consumed package in this scenario. Thus, envelopes are the most impactful in the two categories with higher normalized values, so it should be expected that, envelopes are still the most damaging for the environment, as it will be seen when calculating the single score for this scenario. In scenario 4, given the high disparity in packaging materials consumption, boxes dominate all categories, being the environmental impacts of tape not significant.

Regarding the Impact categories, in all the scenarios marine ecotoxicity is the most impactful category. This is highly related with the production of kraft paper, where most of this impact comes from the energy input to produce the kraft paper. Thus, it is an indicator that the nature and extraction of a product are not enough to evaluate the environmental impacts of a package. The global warming category has a low impact in all the scenarios, so if the environmental performance was only based on this category, all scenarios would be acceptable to be implemented. However, making a more comprehensive overview of environmental impacts, other impact categories appear as way more impactful. In fact, marine ecotoxicity and freshwater ecotoxicity represent about 80% of the contributions for the single score, in all scenarios.

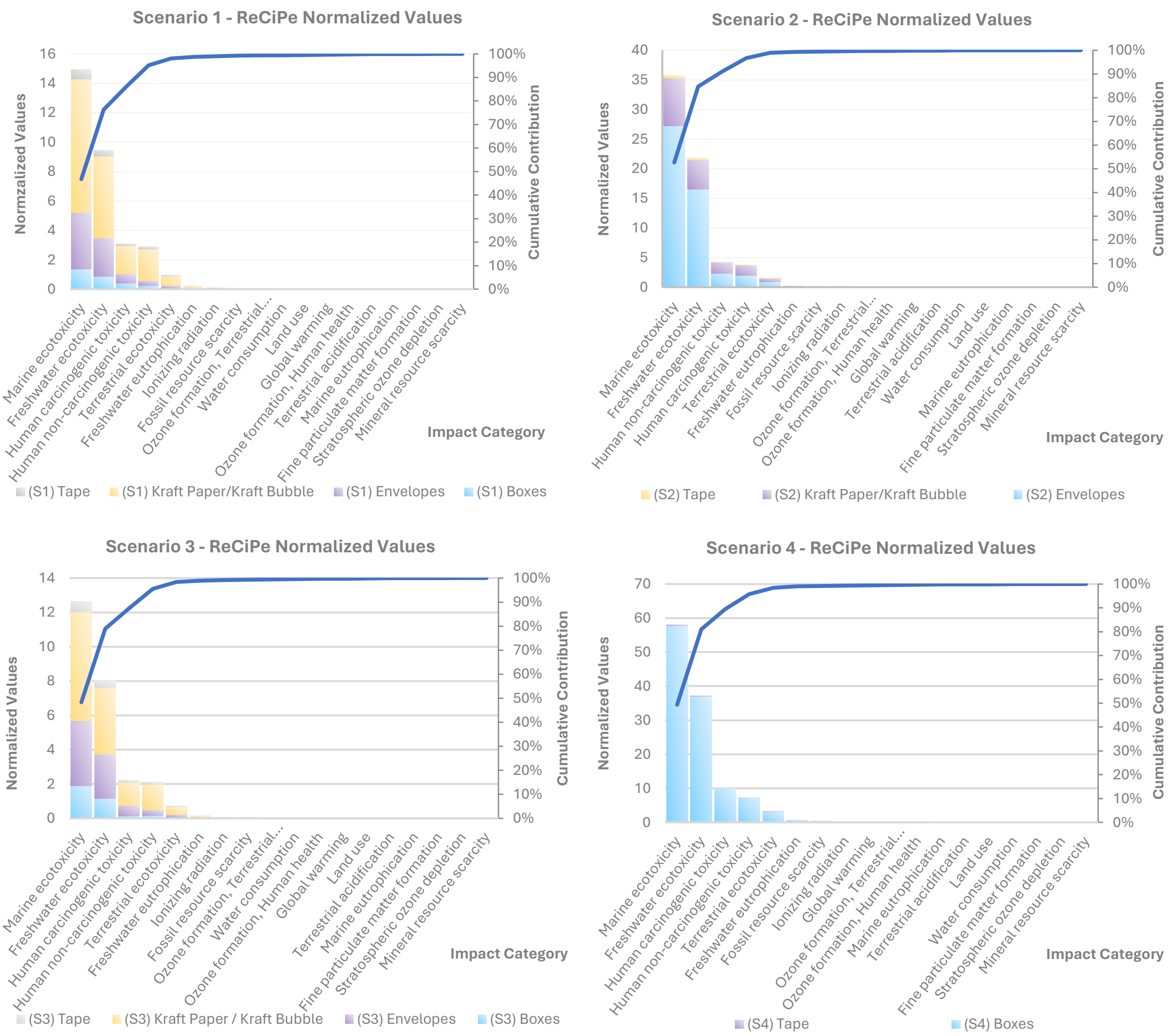


***Figure 34**. Packages contribution for ReCiPe Impact Categories across scenarios, with normalized values.*

To know which option has a lower overall environmental impact and how each package affects the overall environmental performance of a scenario, the single score of each scenario as well as the contribution of each package were determined and are presented in ***Figure 35.***

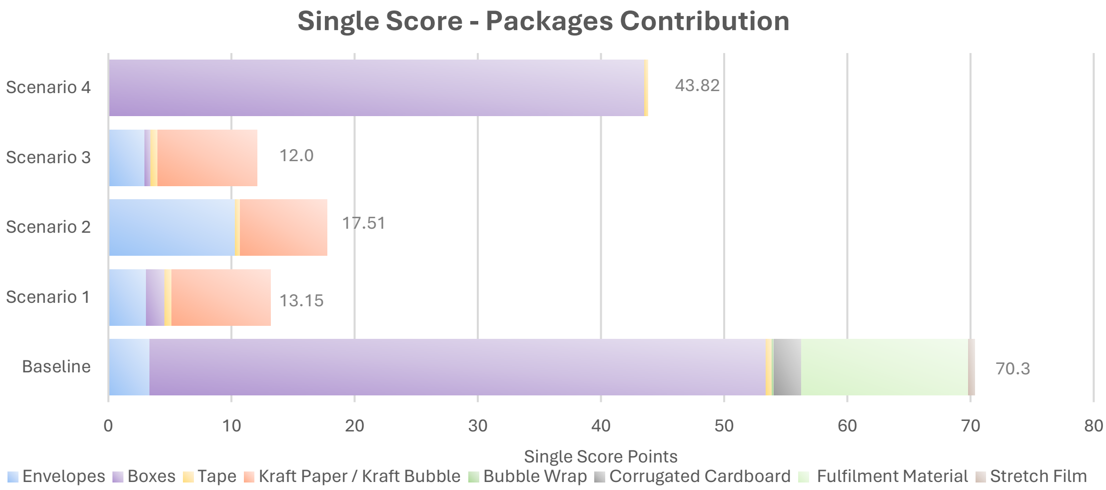


Figure 35. *Single Score across scenarios*

Regarding the single scores in all the scenarios, it is seen that, when compared with the baseline option, all produce better results. The single scores follow the tendency that the more total packaging consumed, the larger the single score is, which is expected. As seen previously, boxes heavily affect the baseline configuration. In the baseline packaging configuration, boxes represent 71.26% of the total single score while representing 60% of total packages consumption. If boxes were environmentally advantageous, this value should be below 60%. However, in scenario 1 for instance, boxes represent only 17.5% of the materials consumption, while impacting 11% of the total single score. This means that, in scenario 1, boxes are used more efficiently. A lesser quantity does not impact as much in proportion. However, in this scenario, envelopes perform poorly, representing 23% of total single score while consuming 10% of the materials.

The same happens for scenario 2, where envelopes corresponded only to 39% of packaging consumption but 58% to the single score. This is related with the cleaning process, which was included in the impacts of reusable envelopes, helping to explain such a big disparity in values. So, all the water wasted in cleaning the packages was also considered. Thus, the end of life of these packages plays a major role. As stated before, due to low return rates and recycle rates of plastics, reusable packages cannot fulfil its full potential. Scenario 3 has the lowest Single Score. The main difference of this value when compared with scenario 1 (the second scenario with the lowest single score) is in the boxes. Scenario 3, despite having more boxes used, since they are reusable, the materials consumption ends up being lower in a yearly basis (6 kg in scenario 3 vs 20 kg in scenario 1).

In ***Figure* 36,** a comparison between costs and environmental impacts is presented. Four quadrants are considered: Lose-Lose (there is at least one scenario with lower values in both objectives), Trade-off (there is at least one scenario with lower values in one of objectives) and Win-win (there is no scenario with lower values in any objective). To a scenario be considered the best option, there is a need to be in the win-win quadrant i.e., has the lower value in both objectives.

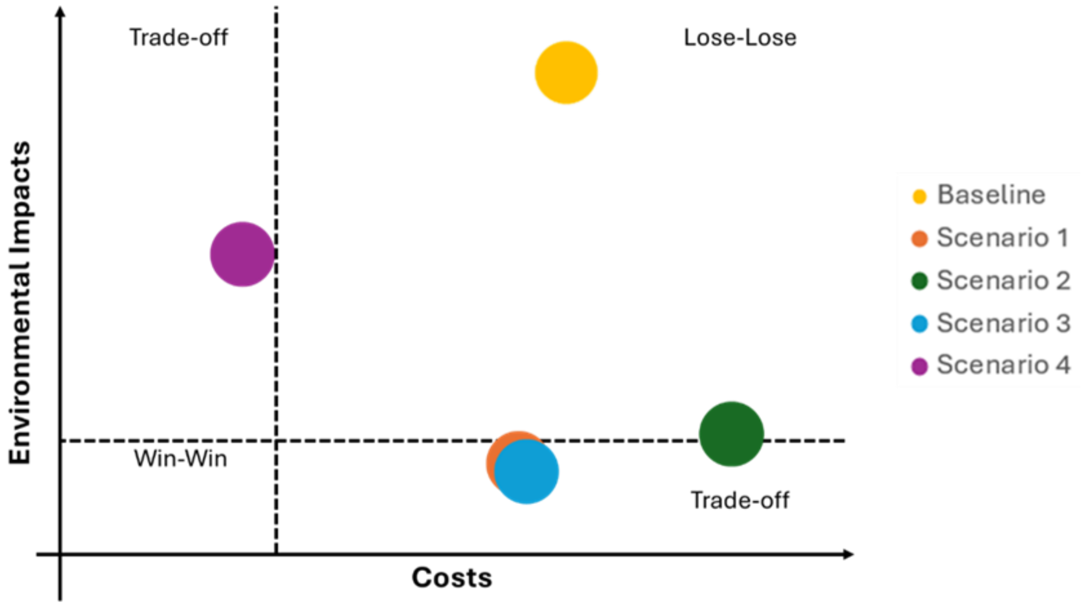


***Figure* 36.** Comparation between baseline and proposed scenarios in the objectives considered.

For the comparison presented it can be concluded that none of the scenarios lay in the win-win quadrant, so there is no dominant scenario. Although, baseline and scenario 2 can be discarded since are in the lose-lose quadrant. Comparing to the baseline, scenarios 1,3 and 4 have lower values in both objectives. On the other hand, scenarios 1 and 3 also have lower values in both objectives when compared with scenario 2. Scenarios 1, 3 and 4 are in the trade-off quadrants. Scenario 3 is the one with lower environmental impacts but also the one with higher costs among these 3 scenarios. Opposingly, Scenario 4 is the one with lower costs but also the one with higher environmental impacts. Scenario 1 presents intermediate values in both objectives. So, the scenario to be chosen will always be dependent on the weight given to each objective.

5.5. Sensitivity Analysis

In this section, several sensitivity analyses on esteemed parameters in the standardization processes , return rates and reuse cycles are done. Firstly, the values where the operators would decide to give an external package to an order or not were changed. Since this value was only based on the observed SKUs, it makes sense to consider products that were not observed, and this change allows to simulate that. Then, the minimal filling rate for boxes was also changed to understand how this value would impact costs, consumptions, and the overall filling rates. Finally, the return rates and reuse cycles were changed in order to understand how reusable packages would behave with higher values.

Changes in the Standardization Process:

- **Threshold value to pack or not:**

Figure 37 presents the values obtained by changing the values of the limit dimension of an order to decide if it is packed with an external packaging or left unpacked. The original values are the ones presented at ***Table 9***. These values were changed within a range spanning from -50% to +50%.

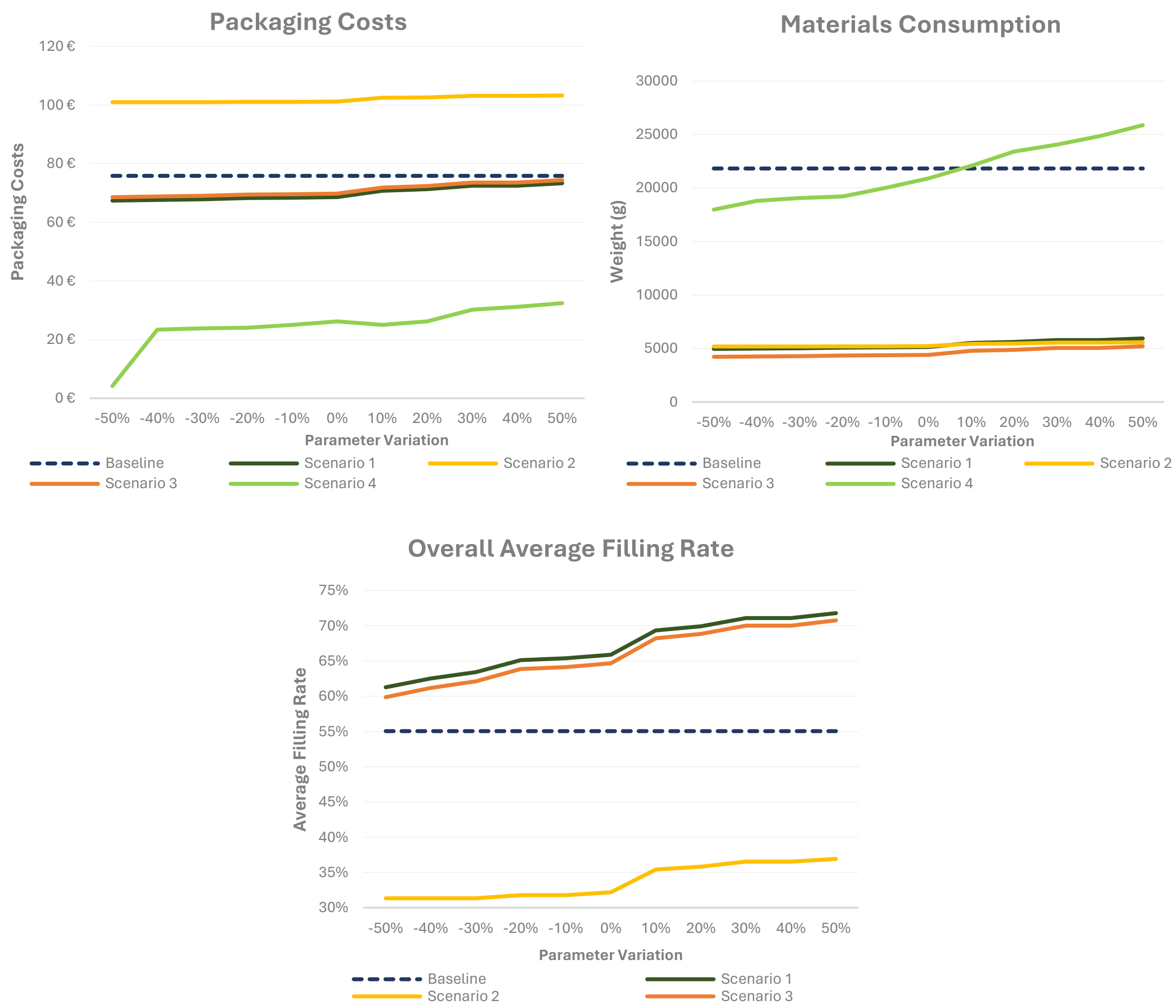


Figure 37*. Sensitivity analysis on the decision value to pack or not a product with external packaging.*

With an increment of these values, the consumption and packaging costs increase, as expected, since the range of orders that are englobed in these dimensions is higher. The costs in scenarios 1, 2, and 3 suffer a small change between a -50% and a +50% variation, being the maximum value in scenario 1 with an 8% increase. These variations do not change the overall performances in all objectives, being the scenario with the lowest values maintained across the three indicators. However, with an even higher increase in this decision values, it is expected that scenarios 1 and 3 become more expensive than the baseline scenario.

Scenario 4 suffers a higher fluctuation in packaging costs, especially between a - 50% and - 40% variation. This happens since in this scenario only the 20 cm dimension is considered. So, this means that a lot of orders have the second larger dimension on the 10 cm range. For materials consumption, scenario 4 is also the most sensitive scenario, suffering an increase of 30%, between a -50% and +50% variation. Scenario 2 consumes less than scenario 1 from a + 9.5% variation in the decision value. This change happens given that this scenario has higher envelope dimensions, so the pool of products that initially use external package is smaller. With the usage of more external packaging, the average filling rates increase, as expected, but do not change the position of each scenario on overall performance of this indicator.

- **Minimum Filling Rate:**

Figure 38 presents the variation in the minimum boxes filling rate at scenario 1. As expected, the decrease of the minimum filling rate impacts the overall value. From a 50% to 0 % minimum value there is a decrease of 11 percentual points in the overall filling rate. However, with no minimum filling rate, this scenario would only have slightly lower values than the baseline scenario (1 percental point). This is easily explained considering that the envelopes used are slightly larger, helping to explain this difference. With the decrease of the minimum filling rate, the material consumptions would increase, as more boxes are going to be used.

From ***Figure 38*** analysis, it is concluded that the values suffer high variations for filling rates lower than 20%. So, this is a sign that below these values, the number of orders that can be packed in boxes increases highly. This will also impact packaging costs on the same manner since the use of boxes is more expensive than the use of external packaging. However, it would be better packed. This inefficiency does not contemplate the need of usage of filling paper, which would increase even more the costs and materials consumptions. However, with a minimal filling rate of 20%, this scenario has higher material consumptions than scenario 2. The increase in packaging costs when the minimum box filling rate is 60% indicates that the costs of using external packaging surpasses the costs of allocating orders that were previously in boxes.

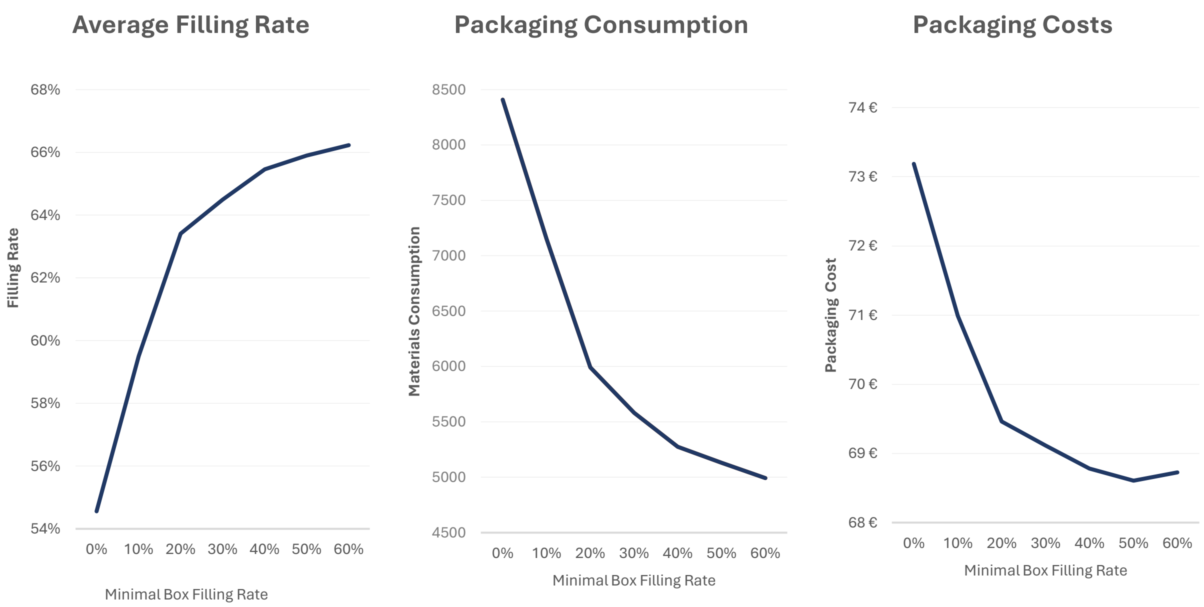


Figure 38. *Variation on boxes minimal filling rate.*

Return Rate and Reuse Cycles:

Figure 39 presents the variation in the packages return rates (from the considered value of 32% in scenarios' analysis to a 75% return rate), considering 20 reuse cycles, and its affects in the packaging costs, materials consumptions, and single score. Only scenarios 2 and 3 were considered since are the ones that use reusable packages. The baseline scenario was not used for comparation in materials consumptions since the initial values are already higher than the scenarios considered.

As expected, the variations in scenario 2 in both criteria are higher. This happens since the number of reusable packages used in this scenario are higher than the ones used in scenario 3. An increase in return rates benefits scenario 2, making it an option with lower packaging costs than baseline configuration and scenario 3 for return rates over 53% and 65% respectively. Considering packaging consumption, for return rates over 56%, scenario 2 consumes less packaging. An increase in return rates leads to a decrease in the single score, going in line with the tendency found for the reduction in materials consumption. For return rates over 57%, scenario 2 has lower values than scenario 1, regarding the single score. However, it never has lower values than scenario 3, opposing to what is observed for packaging costs and materials consumption.

Figure 39. *Return Rates Sensitivity Analysis.*

Reuse cycles were only tested from 10 cycles until 40 cycles since that were the maximum value indicated by RePack, considering that the number of reuse cycles used in scenarios analysis was 20. The variation of reuse cycles has similar effects, regarding packaging consumption, as seen in ***Figure***

40, scenario 2 consumes less than scenario 3 from 34.7 reuse cycles. This change happens for materials consumptions since, proportionally, the difference in weights between reusable and disposal options are higher than the cost differences. However, for packaging costs, scenario 2 never comes cheaper than scenario 3 since the variation in scenario 2 is slightly less when compared with the variation of return rates, but when compared with baseline, it becomes cheaper from 34.8 reuse cycles. Considering environmental impacts, an increase of the return rate makes a high decrease in Scenario 2 single score. This is expected since with more package's reuses, the less packaging is consumed. In fact, scenario 2 gets a lower single score than scenario 1 for values over 35.7 but never gets values lower than scenario 3, which suffers almost no alterations.

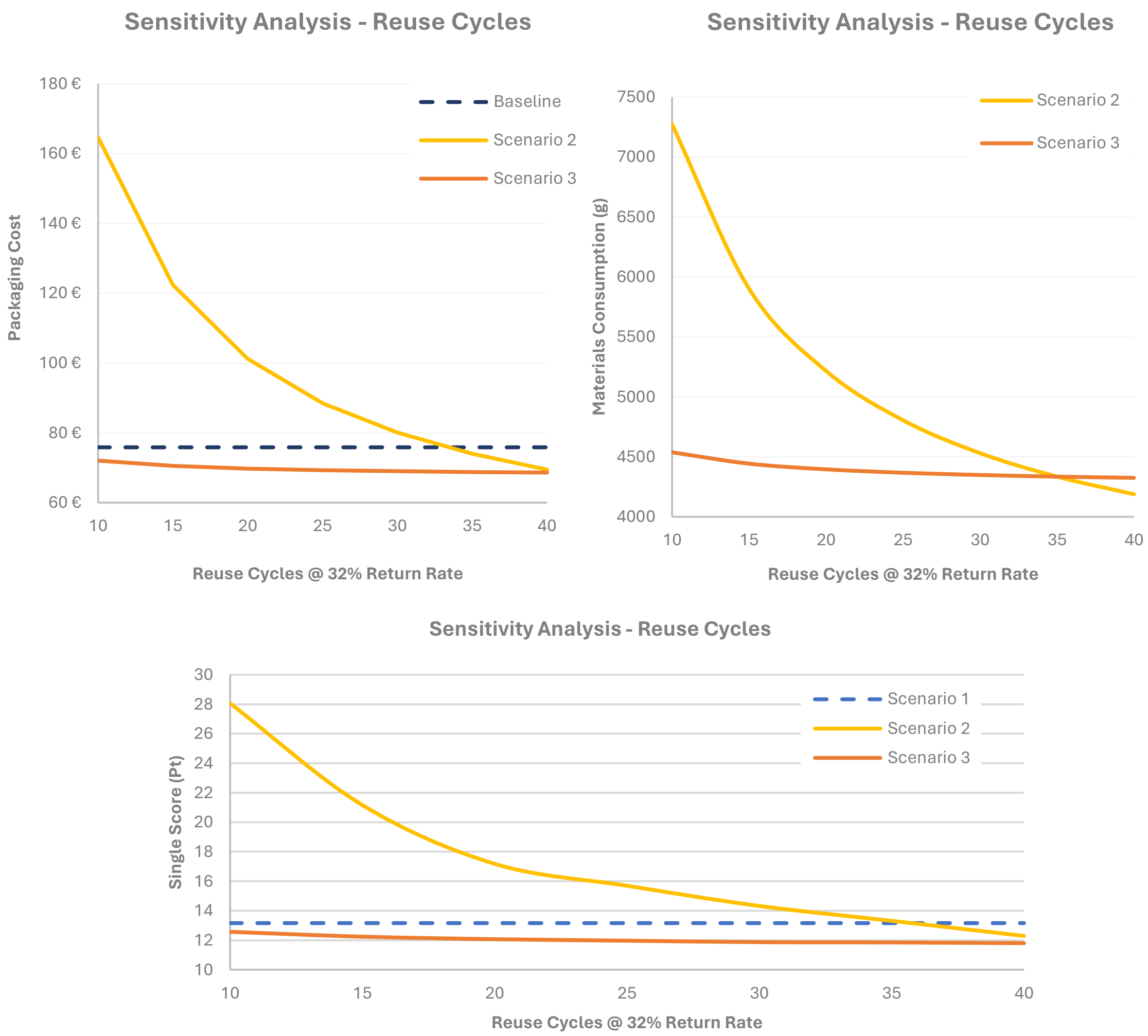


Figure 40. *Reuse Cycles Sensitivity Analysis.*

5.6. Chapter Conclusions

The standardization process to package orders is described. Firstly, there was a need to distinguish which products had a primary package. Then, envelopes played a major role in this process, being the first package to be considered when applying the standardization. Boxes and external packaging were left for products that did not fit the criteria to be packed in an envelope. Considering the process of standardization, the results obtained for the four proposed scenarios were compared with the baseline packaging configuration, which looks to replicate current operation in LMPT e-commerce product packaging.

Regarding the baseline configuration, boxes play a major role, being the most used package. Consequently, they are also the packages that consume the most material. However, when considering packaging costs, filling paper is the option that more contributes for the total costs, but boxes have similar costs. This configuration ends up being the one with the highest single score, when compared with all the proposed scenarios. In all the scenarios, also including the baseline configuration, marine ecotoxicity was the most impactful category. Global warming, which was one of the major concerns of LMPT, has low values in all the scenarios proposed.

In the proposed scenarios, there is none that is dominant in all the objectives proposed (packaging costs, environmental impacts, and materials consumption). Scenario 4 is the one with lower packaging costs but also has the highest material consumption. Scenario 3 has the lowest environmental impacts and packaging materials consumption. Scenarios 1 and 2 have intermediate values in all the objectives. The measure of average packaging filling was also used to evaluate the efficiency of the packages used in each scenario. Considering these values, scenario 4 was excluded from the analysis since it was considered to have 100% of average packaging filling, since each order would be packed exactly according to its dimensions. So, scenario 1 has the highest value, benefiting from the constraint imposed in boxes minimal filling rate. Scenario 3 has similar values, being the only differentiator the elimination of a minimal box filling rate and the change of its nature (from reusable to disposable). Scenario 2 presents the lower values, since majorly envelopes are used in this packaging configuration, and they have larger dimensions, when compared with disposable or compostable envelopes.

6. Conclusions and Future Work

E-commerce has been a growing sales method, so there was a need to address its new challenges, concerning costs and environmental impacts. Product packaging has always been connected with the delivery of orders. Therefore, it was a challenge for LMPT's online operations to optimise the packaging materials' efficiency to reduce costs and environmental effects. A focus was made in home-delivery, where product packaging is fundamental in the majority of orders. To be able to compare the performances in terms of packaging costs, materials consumption, and environmental impacts, several new packages were put forth and combined in various scenarios. LMPT operates in 48 physical stores, and five logistic platforms which support the operations of these stores as well as the online deliveries within each range of operation. Furthermore, there is a dedicated warehouse in Porto Alto exclusively for online deliveries, where observations were carried out to support the standardization processes. The current packaging operation was seen as a problematic due to its NPS value of -12. This was an indicator that LMPT’s customers were generally not satisfied with the packaging of their orders, so there was a need to rethink the way that the packaging of online operations was made. To do so, a standardization process was proposed, looking to minimize consumptions, costs and especially to streamline all the processes across operators. By changing packaging materials, it was looked to reduce the environmental impacts of packaging. It was also implemented the possibility of having reusable packages, in accordance with EU’s prerogatives which by 2030, about 30% of packages in an e-commerce context should be reusable.

Hence, cutting costs was the primary goal of combining the implementation of a standardisation process and changing the packaging materials. The cost structure of the packages in the current packaging operations was heavily weighted towards boxes and the corresponding filling material. But it was also noted that the suggested scenarios were unbalanced. The use of Kraft Paper significantly increased the cost of packaging in Scenarios 1 and 3. The use of reusable envelopes in Scenario 2 and the corrugated cardboard used to package the products in Scenario 4 were the main cost factors. The total packaging costs obtained contrast with most of the reviewed literature, which suggested that using reusable options (Scenario 2) would be more cost-effective. However, scenario 2 is the one who has the most costs. Since this could be explained to low return rates and reuse cycles, a sensitivity analysis was conducted in these parameters. It was observed that, by increasing both values, scenario 2 could have more competitive costs but would never be the option with lower costs. Thus, cleaning and transportation costs were not included in these scenarios, which would account for even higher values.

The second objective was to reduce materials consumption. By doing this, less waste would be generated and the green dot value to be paid would be lower. The implementation of a standardized process, would, as intended, highly reduce the materials consumption. In all the proposed scenarios where manual packaging was considered, materials consumption is lower than the one that exists in current packaging operations. By shifting the usage of boxes, to external packaging, this reduction was observed. The main differences in each scenario lay in the individual weights of the used envelopes and boxes (reusable, compostable or disposable). Regarding this objective, scenario 3 was the one with lower materials consumed and scenario 4 the one with the most consumed. This happened since, in automated packaging (scenario 4) the majority of products were packed using cardboard.

The third objective was to reduce environmental impacts of the packaging process. By using the SimaPro software and the ReCiPe Methodology a comparation between scenarios was made regarding the different impact categories and the overall scenarios environmental performances. One of the main focuses of LMPT is carbon neutrality, and for that matter, the impact category global warming takes great importance. However, in all scenarios (including the baseline configuration), this value is low, so other impact categories are more relevant when considering packaging. It was observed that the most impactful categories were related with the impact on water quality, which had a higher impact in human health rather than in ecosystems. By looking at the single scores, scenario 3 was the one with the lowest value, while scenario 4 was the one with the highest considering the scenarios proposed. The current packaging configuration has the highest single score when compared with all the scenarios.

The average filling rate of a package was used as a metric to understand if a package was being used in an efficient manner. Scenarios 1,3 and 4 present higher values when compared with the baseline packaging configuration. By having higher values, it is expected that the problem of overpackaging is reduced and the NPS value could be increased. Scenario 2 is the only configuration where the values are lower than the baseline configuration.

Considering the three main objectives, none of the scenarios presented has the lowest value in all. In costs, scenario 4 is the one who presents the lower values. However, it is the one with the highest values in materials consumptions and single score. Scenario 3 is the one with the lower values in materials consumption and environmental impacts. Scenario 1 does not have the lowest value in none of the objectives. Scenario 2 is the one with highest costs. Nevertheless, the obtention of these results has limitations: Some values may have been estimated inaccurately, such as orders dimensions or several packaging costs, so it may reflect in different values than the actual ones. The observation span was also small, when compared with the actual number of home delivery orders made by LMPT, so the orders considered may not be a completely accurate estimation of the orders made. It was also difficult to estimate the cost and impacts of a new logistics structure regarding the reusable packages. The value of the automation machine was not defined, and its ROI may put this option as non-viable. Thus, the approximations made in SimaPro may lead to some inaccurate results.

For future work, it would be interesting to implement this standardization process and made possible adjustments accordingly with operators and clients' feedback. Thus, this standardization process should be extended to pick up in store online orders. This was not made in this dissertation since the observations made were exclusive to home delivery. Costs regarding the transportation of reusable packages to the warehouses, its cleaning, and a caution value to return the packages should be studied and added into reusable costs accountability. A minimum filling rate for envelopes could also be studied.

References

Abejón, R., Bala, A., Vázquez-Rowe, I., Aldaco, R., & Fullana-i-Palmer, P. (2020). When plastic packaging should be preferred: Life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. *Resources, Conservation and Recycling*, *155*. https://doi.org/10.1016/j.resconrec.2019.104666

Accorsi, R., Baruffaldi, G., & Manzini, R. (2020). A closed-loop packaging network design model to foster infinitely reusable and recyclable containers in food industry. *Sustainable Production and Consumption*, *24*, 48–61. https://doi.org/10.1016/j.spc.2020.06.014

Ahamed, A., Vallam, P., Iyer, N. S., Veksha, A., Bobacka, J., & Lisak, G. (2021). Life cycle assessment of plastic grocery bags and their alternatives in cities with confined waste management structure: A Singapore case study. *Journal of Cleaner Production*, *278*. https://doi.org/10.1016/j.jclepro.2020.123956

APA. (2023). *RECICLAGEM DE RESÍDUOS DE EMBALAGENS*. Retrieved (August 2,2023) https://rea.apambiente.pt/content/reciclagem-de-res%C3%ADduos-de-embalagens

Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). Products that go round: Exploring product life extension through design. *Journal of Cleaner Production*, *69*, 10–16. https://doi.org/10.1016/j.jclepro.2014.01.028

Bălăcescu, A., Pătrașcu, A., & Tănăsescu, A. (2023). Analysis of Disparities in Internet Purchases by Individuals at the EU State Level. *Electronics (Switzerland)*, *12*(4). https://doi.org/10.3390/electronics12040982

Bask, A. H. (2001.). *Relationships among TPL providers and members of supply chains ± a strategic perspective*. http://www.emerald-library.com/ft

Bassani, F., Rodrigues, C., Marques, P., & Freire, F. (2022). Ecodesign approach for pharmaceutical packaging based on Life Cycle Assessment. *Science of the Total Environment*, *816*. https://doi.org/10.1016/j.scitotenv.2021.151565

Beck, N., & Rygl, D. (2015). Categorization of multiple channel retailing in Multi-, Cross-, and Omni-Channel Retailing for retailers and retailing. *Journal of Retailing and Consumer Services*, *27*, 170–178. https://doi.org/10.1016/j.jretconser.2015.08.001

Bell, D. R., Gallino, S., & Moreno, A. (2018). Offline showrooms in omnichannel retail: Demand and operational benefits. *Management Science*, *64*(4), 1629–1651. https://doi.org/10.1287/mnsc.2016.2684

Bening, C. R., Pruess, J. T., & Blum, N. U. (2021). Towards a circular plastics economy: Interacting barriers and contested solutions for flexible packaging recycling. *Journal of Cleaner Production*, *302*. https://doi.org/10.1016/j.jclepro.2021.126966

Cao, L., & Li, L. (2015). The Impact of Cross-Channel Integration on Retailers' Sales Growth. *Journal of Retailing*, *91*(2), 198–216. https://doi.org/10.1016/j.jretai.2014.12.005

Coates, G. W., & Getzler, Y. D. Y. L. (2020). Chemical recycling to monomer for an ideal, circular polymer economy. In *Nature Reviews Materials* (Vol. 5, Issue 7, pp. 501–516). Nature Research. https://doi.org/10.1038/s41578-020-0190-4

Cobb, B. R. (2016). Inventory control for returnable transport items in a closed-loop supply chain. *Transportation Research Part E: Logistics and Transportation Review*, *86*, 53–68. https://doi.org/10.1016/j.tre.2015.12.010

Coelho, P. M., Corona, B., ten Klooster, R., & Worrell, E. (2020). Sustainability of reusable packaging–Current situation and trends. In *Resources, Conservation and Recycling: X* (Vol. 6). Elsevier B.V. https://doi.org/10.1016/j.rcrx.2020.100037

Cottafava, D., Costamagna, M., Baricco, M., Corazza, L., Miceli, D., & Riccardo, L. E. (2021). Assessment of the environmental break-even point for deposit return systems through an LCA analysis of single-use and reusable cups. *Sustainable Production and Consumption*, *27*, 228–241. https://doi.org/10.1016/j.spc.2020.11.002

den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. *Journal of Industrial Ecology*, *21*(3), 517–525. https://doi.org/10.1111/jiec.12610

Elias, H., & Mülhaupt, R. (2015). Plastics, General Survey, 5. Plastics and Sustainability. In *Ullmann's Encyclopedia of Industrial Chemistry* (pp. 1–7). Wiley. https://doi.org/10.1002/14356007.t20_t04

Ellen MacArthur Foundation. (2019). *Reuse – rethinking packaging*. Retrieved (June 12, 2023) https://ellenmacarthurfoundation.org/reuse-rethinking-packaging

Ellen MacArthur Foundation. (2020). *Upstream Innovation - A guide to packaging solutions*. Retrieved (August 5, 2023) https://emf.thirdlight.com/file/24/h_Pf1MahttEqT6h_OwchCrKU2/Upstream%20Innovation.pdf

Eriksen, M. K., Christiansen, J. D., Daugaard, A. E., & Astrup, T. F. (2019). Closing the loop for PET, PE and PP waste from households: Influence of material properties and product design for plastic recycling. *Waste Management*, *96*, 75–85. https://doi.org/10.1016/j.wasman.2019.07.005

Escursell, S., Llorach-Massana, P., & Roncero, M. B. (2021). Sustainability in e-commerce packaging: A review. In *Journal of Cleaner Production* (Vol. 280). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.124314

EU. (2018). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)*. https://eur-lex.europa.eu/eli/dir/2008/98/oj/eng

EU. (2019). *D2.3: Reference methodologies and KPIs in circular economy analysis*. https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5c8e38027&appId=PPGMS

EU. (2022). *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0677

European Parliament. (2023). *Revision of the Packaging and Packaging Waste Directive*. https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/745707/EPRS_BRI(2023)745707_EN.pdf

Eurostat. (2019). *Glossary:E-commerce*. Retrieved (May 20 2023) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:E-commerce

Eurostat. (2023). *E-commerce continues to grow in the EU*. Retrieved (May 9, 2023) https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230228-2

Fibre Box. (2021). *Corrugated vs. Plastic Packaging*. Retrieved (May 29, 2023 https://www.fibrebox.org/corrugated-vs-rpcs

Frank, B. (2014). Corrugated box compression - A literature survey. In *Packaging Technology and Science* (Vol. 27, Issue 2, pp. 105–128). https://doi.org/10.1002/pts.2019

Gao, F., & Su, X. (2017). Omnichannel retail operations with buy-online-and-pick-up-in-store. *Management Science*, *63*(8), 2478–2492. https://doi.org/10.1287/mnsc.2016.2473

Garbowski, T., Gajewski, T., & Grabski, J. K. (2021). Estimation of the compressive strength of corrugated cardboard boxes with various perforations. *Energies*, *14*(4). https://doi.org/10.3390/en14041095

Gardas, B. B., Raut, R. D., & Narkhede, B. (2019). Identifying critical success factors to facilitate reusable plastic packaging towards sustainable supply chain management. *Journal of Environmental Management*, *236*, 81–92. https://doi.org/10.1016/j.jenvman.2019.01.113

Garofalo, E., Di Maio, L., Scarfato, P., Di Gregorio, F., & Incarnato, L. (2018). Reactive compatibilization and melt compounding with nanosilicates of post-consumer flexible plastic packagings. *Polymer Degradation and Stability*, *152*, 52–63. https://doi.org/10.1016/j.polymdegradstab.2018.03.019

Gatt, I. J., & Refalo, P. (2022). Reusability and recyclability of plastic cosmetic packaging: A life cycle assessment. *Resources, Conservation and Recycling Advances*, *15*. https://doi.org/10.1016/j.rcradv.2022.200098

Gefen, D. (2000.). *E-commerce: the role of familiarity and trust*. www.elsevier.com/locate/dsw

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? In *Journal of Cleaner Production* (Vol. 143, pp. 757–768). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2016.12.048

Geueke, B., Groh, K., & Muncke, J. (2018). Food packaging in the circular economy: Overview of chemical safety aspects for commonly used materials. In *Journal of Cleaner Production* (Vol. 193, pp. 491–505). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2018.05.005

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). *Production, use, and fate of all plastics ever made*. Science Advances, 3(7) https://www.science.org/doi/10.1126/sciadv.1700782

Glock, C. H., & Kim, T. (2014). Container management in a single-vendor-multiple-buyer supply chain. *Logistics Research*, *7*(1). https://doi.org/10.1007/s12159-014-0112-1

Goedkoop, M., Heijungs, R., De Schryver, A., Struijs, J., & Van Zelm, R. (2013). *ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level First edition (version 1.08) Report I: Characterisation Mark Huijbregts 3)*.

Grdic, Z. S., Nizic, M. K., & Rudan, E. (2020). Circular economy concept in the context of economic development in EU countries. *Sustainability (Switzerland)*, *12*(7). https://doi.org/10.3390/su12073060

Hahladakis, J. N., Velis, C. A., Weber, R., Iacovidou, E., & Purnell, P. (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. In *Journal of Hazardous Materials* (Vol. 344, pp. 179–199). Elsevier B.V. https://doi.org/10.1016/j.jhazmat.2017.10.014

Han, J., & Park, J. M. (2007). Finite element analysis of vent/hand hole designs for corrugated fibreboard boxes. *Packaging Technology and Science*, *20*(1), 39–47. https://doi.org/10.1002/pts.741

He, P., Zhang, S., & He, C. (2019). Impacts of logistics resource sharing on B2C E-commerce companies and customers. *Electronic Commerce Research and Applications*, *34*. https://doi.org/10.1016/j.elerap.2018.100820

Herbes, C., Beuthner, C., & Ramme, I. (2018). Consumer attitudes towards biobased packaging – A cross-cultural comparative study. *Journal of Cleaner Production*, *194*, 203–218. https://doi.org/10.1016/j.jclepro.2018.05.106

Herhausen, D., Binder, J., Schoegel, M., & Herrmann, A. (2015). Integrating Bricks with Clicks: Retailer-Level and Channel-Level Outcomes of Online-Offline Channel Integration. *Journal of Retailing*, *91*(2), 309–325. https://doi.org/10.1016/j.jretai.2014.12.009

Holdway, R., Walker, D., & Hilton, M. (2010). Eco-design and successful packaging. *Design Management Journal (Former Series)*, *13*(4), 45–53. https://doi.org/10.1111/j.1948-7169.2002.tb00330.x

Horodytska, O., Valdés, F. J., & Fullana, A. (2018). Plastic flexible films waste management – A state of art review. In *Waste Management* (Vol. 77, pp. 413–425). Elsevier Ltd. https://doi.org/10.1016/j.wasman.2018.04.023

Huang, L., Lu, X., & Ba, S. (2016). An empirical study of the cross-channel effects between web and mobile shopping channels. *Information and Management*, *53*(2), 265–278. https://doi.org/10.1016/j.im.2015.10.006

Hübner, A., Wollenburg, J., & Holzapfel, A. (2016). Retail logistics in the transition from multi-channel to omni-channel. *International Journal of Physical Distribution and Logistics Management*, *46*(6–7), 562–583. https://doi.org/10.1108/IJPDLM-08-2015-0179

Huijbregts, M. A. J., Steinmann, Z. J. N., Elshout, P. M. F., Stam, G., Verones, F., Vieira, M., Zijp, M., Hollander, A., & van Zelm, R. (2017). ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. *International Journal of Life Cycle Assessment*, *22*(2), 138–147. https://doi.org/10.1007/s11367-016-1246-y

Huseynov, F., & Özkan Yıldırım, S. (2019). Online Consumer Typologies and Their Shopping Behaviors in B2C E-Commerce Platforms. *SAGE Open*, *9*(2). https://doi.org/10.1177/2158244019854639

ISO. (2006). *ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework*. https://www.iso.org/standard/37456.html

Kaab, A., Sharifi, M., Mobli, H., Nabavi-Pelesaraei, A., & Chau, K. wing. (2019). Use of optimization techniques for energy use efficiency and environmental life cycle assessment modification in sugarcane production. *Energy*, *181*, 1298–1320. https://doi.org/10.1016/j.energy.2019.06.002

Kan, M., & Miller, S. A. (2022). Environmental impacts of plastic packaging of food products. *Resources, Conservation and Recycling*, *180*. https://doi.org/10.1016/j.resconrec.2022.106156

Kim, R. Y. (2020). The Impact of COVID-19 on Consumers: Preparing for Digital Sales. *IEEE Engineering Management Review*, *48*(3), 212–218. https://doi.org/10.1109/EMR.2020.2990115

Kim, Y., & Peterson, R. A. (2017). A Meta-analysis of Online Trust Relationships in E-commerce. *Journal of Interactive Marketing*, *38*, 44–54. https://doi.org/10.1016/j.intmar.2017.01.001

Klooster, I. (2002). Package design: A methodical development and simulation of the design process. https://repository.tudelft.nl/islandora/object/uuid:975bece7-ae11-4d3d-a501-79da7e4c5ca8?collection=research

Koskela, S., Dahlbo, H., Judl, J., Korhonen, M. R., & Niininen, M. (2014). Reusable plastic crate or recyclable cardboard box? A comparison of two delivery systems. *Journal of Cleaner Production*, *69*, 83–90. https://doi.org/10.1016/j.jclepro.2014.01.045

Leminen, V., Tanninen, P., Pesonen, A., & Varis, J. (2019). Effect of mechanical perforation on the press-forming process of paperboard. *Procedia Manufacturing*, *38*, 1402–1408. https://doi.org/10.1016/j.promfg.2020.01.148

Lewandowski, M. (2016). Designing the business models for circular economy-towards the conceptual framework. In *Sustainability (Switzerland)* (Vol. 8, Issue 1). MDPI. https://doi.org/10.3390/su8010043

Lieb, R. C., Millen, R. A., & Van Wassenhove, L. N. (1993). Third-party Logistics Services: A Comparison of Experienced American and European Manufacturers. In *International Journal of Physical Distribution & Logistics Management* (Vol. 23, Issue 6).

Lindh, H., Williams, H., Olsson, A., & Wikström, F. (2016). Elucidating the Indirect Contributions of Packaging to Sustainable Development: A Terminology of Packaging Functions and Features. In *Packaging Technology and Science* (Vol. 29, Issues 4–5, pp. 225–246). John Wiley and Sons Ltd. https://doi.org/10.1002/pts.2197

Lu, S., Yang, L., Liu, W., & Jia, L. (2020). User preference for electronic commerce overpackaging solutions: Implications for cleaner production. *Journal of Cleaner Production*, *258*. https://doi.org/10.1016/j.jclepro.2020.120936

Luzi, F., Torre, L., Kenny, J. M., & Puglia, D. (2019). Bio- and fossil-based polymeric blends and nanocomposites for packaging: Structure-property relationship. In *Materials* (Vol. 12, Issue 3). MDPI AG. https://doi.org/10.3390/ma12030471

Mangiaracina, R., Perego, A., Seghezzi, A., & Tumino, A. (2019). Innovative solutions to increase last-mile delivery efficiency in B2C e-commerce: a literature review. In *International Journal of Physical Distribution and Logistics Management* (Vol. 49, Issue 9, pp. 901–920). Emerald Group Holdings Ltd. https://doi.org/10.1108/IJPDLM-02-2019-0048

Meherishi, L., Narayana, S. A., & Ranjani, K. S. (2019). Sustainable packaging for supply chain management in the circular economy: A review. *Journal of Cleaner Production*, *237*. https://doi.org/10.1016/j.jclepro.2019.07.057

Mendoza, J. M. F., Sharmina, M., Gallego-Schmid, A., Heyes, G., & Azapagic, A. (2017). Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework. *Journal of Industrial Ecology*, *21*(3), 526–544. https://doi.org/10.1111/jiec.12590

Merrild, H., Damgaard, A., & Christensen, T. H. (2009). Recycling of paper: Accounting of greenhouse gases and global warming contributions. In *Waste Management and Research* (Vol. 27, Issue 8, pp. 746–753). https://doi.org/10.1177/0734242X09348530

Morganti, E., Dablanc, L., & Fortin, F. (2014). Final deliveries for online shopping: The deployment of pickup point networks in urban and suburban areas. *Research in Transportation Business and Management*, *11*, 23–31. https://doi.org/10.1016/j.rtbm.2014.03.002

Moroz, M., & Polkowski, Z. (2016). The Last Mile Issue and Urban Logistics: Choosing Parcel Machines in the Context of the Ecological Attitudes of the Y Generation Consumers Purchasing Online. *Transportation Research Procedia*, *16*, 378–393. https://doi.org/10.1016/j.trpro.2016.11.036

Mrówczyński, D., Knitter-Piątkowska, A., & Garbowski, T. (2022). Optimal Design of Double-Walled Corrugated Board Packaging. *Materials*, *15*(6). https://doi.org/10.3390/ma15062149

Mura, M., Longo, M., & Zanni, S. (2020). Circular economy in Italian SMEs: A multi-method study. *Journal of Cleaner Production*, *245*. https://doi.org/10.1016/j.jclepro.2019.118821

Neslin, S. A., Grewal, D., Leghorn, R., Shankar, V., Teerling, M. L., Thomas, J. S., & Verhoef, P. C. (2006). Challenges and opportunities in multichannel customer management. In *Journal of Service Research* (Vol. 9, Issue 2, pp. 95–112). SAGE Publications Inc. https://doi.org/10.1177/1094670506293559

Noissue. (2022). *The Ultimate Guide to Compostable Packaging Materials*. Retrieved (July 23,2023) https://noissue.co/blog/the-ultimate-guide-to-compostable-packaging-materials/

Pålsson, H., Finnsgård, C., & Wänström, C. (2013). Selection of packaging systems in supply chains from a sustainability perspective: The case of volvo. *Packaging Technology and Science*, *26*(5), 289–310. https://doi.org/10.1002/pts.1979

Pålsson, H., Pettersson, F., & Winslott Hiselius, L. (2017). Energy consumption in e-commerce versus conventional trade channels - Insights into packaging, the last mile, unsold products and product returns. *Journal of Cleaner Production*, *164*, 765–778. https://doi.org/10.1016/j.jclepro.2017.06.242

Pålsson, H., & Olsson, J. (2023). Current state and research directions for disposable versus reusable packaging: A systematic literature review of comparative studies. *Packaging Technology and Science*. https://doi.org/10.1002/pts.2722

Pappas, I. O. (2018). User experience in personalized online shopping: a fuzzy-set analysis. *European Journal of Marketing*, *52*(7–8), 1679–1703. https://doi.org/10.1108/EJM-10-2017-0707

Peças, P., Ribeiro, I., Silva, A., & Henriques, E. (2013). Comprehensive approach for informed life cycle-based materials selection. *Materials and Design*, *43*, 220–232. https://doi.org/10.1016/j.matdes.2012.06.064

Piotrowicz, W., & Cuthbertson, R. (2014). Introduction to the special issue information technology in retail: Toward omnichannel retailing. In *International Journal of Electronic Commerce* (Vol. 18, Issue 4, pp. 5–16). M.E. Sharpe Inc. https://doi.org/10.2753/JEC1086-4415180400

Reichheld, F. F. (2003). *The One Number You Need to Grow*. Harvard Business Review. 81. 46-54, 124. www.hbr.org

Roithner, C., & Rechberger, H. (2020). Implementing the dimension of quality into the conventional quantitative definition of recycling rates. *Waste Management*, *105*, 586–593. https://doi.org/10.1016/j.wasman.2020.02.034

Rosario, A. B., Sotgiu, F., De Valck, K., & Bijmolt, T. H. A. (2016). The effect of electronic word of mouth on sales: A meta-analytic review of platform, product, and metric factors. *Journal of Marketing Research*, *53*(3), 297–318. https://doi.org/10.1509/jmr.14.0380

Rosenboom, J. G., Langer, R., & Traverso, G. (2022). Bioplastics for a circular economy. In *Nature Reviews Materials* (Vol. 7, Issue 2, pp. 117–137). Nature Research. https://doi.org/10.1038/s41578-021-00407-8

Sadat-Shojai, M., & Bakhshandeh, G. R. (2011). Recycling of PVC wastes. In *Polymer Degradation and Stability* (Vol. 96, Issue 4, pp. 404–415). https://doi.org/10.1016/j.polymdegradstab.2010.12.001

Selke, S. E. M., & Culter, J. D. (2016). Major Plastics in Packaging. In *Plastics Packaging* (pp. 101–157). Carl Hanser Verlag GmbH & Co. KG. https://doi.org/10.3139/9783446437197.004

Sevigné-Itoiz, E., Gasol, C. M., Rieradevall, J., & Gabarrell, X. (2015). Methodology of supporting decision-making of waste management with material flow analysis (MFA) and consequential life cycle assessment (CLCA): Case study of waste paper recycling. *Journal of Cleaner Production*, *105*, 253–262. https://doi.org/10.1016/j.jclepro.2014.07.026

Shi, F. (2017). Omni-Channel Retailing: Knowledge, Challenges, and Opportunities for Future Research. In *Developments in Marketing Science: Proceedings of the Academy of Marketing Science* (pp. 91–102). Springer Nature. https://doi.org/10.1007/978-3-319-47331-4_18

Sijtsema, S. J., Snoek, H. M., van Haaster-de Winter, M. A., & Dagevos, H. (2020). Let's talk about circular economy: A qualitative exploration of consumer perceptions. *Sustainability (Switzerland)*, *12*(1). https://doi.org/10.3390/su12010286

Silva, D. A. L., Renó, G. W. S., Sevegnani, G., Sevegnani, T. B., & Truzzi, O. M. S. (2013). Comparison of disposable and returnable packaging: A case study of reverse logistics in Brazil. *Journal of Cleaner Production*, *47*, 377–387. https://doi.org/10.1016/j.jclepro.2012.07.057

Silva, S. C. e., Martins, C. C., & Sousa, J. M. de. (2018). Omnichannel approach: Factors affecting consumer acceptance. *Journal of Marketing Channels*, *25*(1–2), 73–84. https://doi.org/10.1080/1046669X.2019.1647910

Simms, C., Trott, P., Hende, E. van den, & Hultink, E. J. (2020). Barriers to the adoption of waste-reducing eco-innovations in the packaged food sector: A study in the UK and the Netherlands. *Journal of Cleaner Production*, *244*. https://doi.org/10.1016/j.jclepro.2019.118792

Singh, N., Hui, D., Singh, R., Ahuja, I. P. S., Feo, L., & Fraternali, F. (2017). Recycling of plastic solid waste: A state of art review and future applications. *Composites Part B: Engineering*, *115*, 409–422. https://doi.org/10.1016/j.compositesb.2016.09.013

Siracusa, V., Rosa, M. D., Romani, S., Rocculi, P., & Tylewicz, U. (2011). Life Cycle Assessment of multilayer polymer film used on food packaging field. *Procedia Food Science*, *1*, 235–239. https://doi.org/10.1016/j.profoo.2011.09.037

Sparck Technologies. (2021). *Let's talk about automated packaging - Meet the CVP Impack & CVP Everest*. Retrieved (August 13, 2023) https://sparcktechnologies.com/wp-content/uploads/2021/09/CVP-Impack-Brochure_UK.pdf

Statista. (2019). *The Return of the Package*. Retrieved (August 7,2023) https://www.statista.com/chart/16615/e-commerce-product-return-rate-in-europe/

Statista. (2022). *Distribution of packaging demand worldwide in 2019, by material type*. Retrieved (June 3,2023) https://www.statista.com/statistics/271601/packaging-materials-in-the-global-packaging-market-since-2003/

Suhas, Gupta, V. K., Carrott, P. J. M., Singh, R., Chaudhary, M., & Kushwaha, S. (2016). Cellulose: A review as natural, modified and activated carbon adsorbent. In *Bioresource Technology* (Vol. 216, pp. 1066–1076). Elsevier Ltd. https://doi.org/10.1016/j.biortech.2016.05.106

Tamburini, E., Costa, S., Summa, D., Battistella, L., Fano, E. A., & Castaldelli, G. (2021). Plastic (PET) vs bioplastic (PLA) or refillable aluminium bottles – What is the most sustainable choice for drinking water? A life-cycle (LCA) analysis. *Environmental Research*, *196*. https://doi.org/10.1016/j.envres.2021.110974

Van Laarhoven, P., Berglund, M., & Peters, M. (2000). Third-party logistics in Europe Third-party logistics in Europe ± five years later. In *International Journal of Physical Distribution & Logistics Management* (Vol. 30, Issue 5). # MCB University Press. http://www.emerald-library.com

Verghese, K., & Lewis, H. (2007). Environmental innovation in industrial packaging: A supply chain approach. *International Journal of Production Research*, *45*(18–19), 4381–4401. https://doi.org/10.1080/00207540701450211

Verhoef, P. C., Kannan, P. K., & Inman, J. J. (2015). From Multi-Channel Retailing to Omni-Channel Retailing. Introduction to the Special Issue on Multi-Channel Retailing. *Journal of Retailing*, *91*(2), 174–181. https://doi.org/10.1016/j.jretai.2015.02.005

Vilarinho, F., Sanches Silva, A., Vaz, M. F., & Farinha, J. P. (2018). Nanocellulose in green food packaging. *Critical Reviews in Food Science and Nutrition*, *58*(9), 1526–1537. https://doi.org/10.1080/10408398.2016.1270254

Wagner, J. R. (2016). Blown Film, Cast Film, and Lamination Processes. In *Multilayer Flexible Packaging: Second Edition* (pp. 137–145). Elsevier Inc. https://doi.org/10.1016/B978-0-323-37100-1.00010-7

Waliszewski, K., & Warchlewska, A. (2021). Comparative analysis of Poland and selected countries in terms of household financial behaviour during the COVID-19 pandemic JEL Classification: C13; C22; C53; F31; D10. *Equilibrium. Quarterly Journal of Economics and Economic Policy*, *16*. https://doi.org/10.2413

Wang, H., Huang, M., Ip, W. H., & Wang, X. (2021). Network design for maximizing service satisfaction of suppliers and customers under limited budget for industry innovator fourth-party logistics. *Computers and Industrial Engineering*, *158*. https://doi.org/10.1016/j.cie.2021.107404

Weller, I., Süß, J., Evanschitzky, H., & von Wangenheim, F. (2020). Transformational Leadership, High-Performance Work System Consensus, and Customer Satisfaction. *Journal of Management*, *46*(8), 1469–1497. https://doi.org/10.1177/0149206318817605

Yu, Y., Wang, X., Zhong, R. Y., & Huang, G. Q. (2016). E-commerce Logistics in Supply Chain Management: Practice Perspective. *Procedia CIRP*, *52*, 179–185. https://doi.org/10.1016/j.procir.2016.08.002

Zhou, L., Wang, W., Xu, J. (David), Liu, T., & Gu, J. (2018). Perceived information transparency in B2C e-commerce: An empirical investigation. *Information and Management*, *55*(7), 912–927. https://doi.org/10.1016/j.im.2018.04.005

Zimmermann, T., & Bliklen, R. (2020). Single-use vs. reusable packaging in e-commerce: Comparing carbon footprints and identifying break-even points. *GAIA - Ecological Perspectives for Science and Society*, *29*(3), 176–183. https://doi.org/10.14512/GAIA.29.3.8

Zwass, V. (1996). *Electronic Commerce: Structures and Issues*. International Journal of Electronic Commerce. 1(1), 3-23. https://www.jstor.org/stable/27750797

Appendix

Appendix 1 – Packages Information

A.1.1. Used Packages Values

Name	Dimensions [mm]	Cost	Supplier	Weight (g)	Material		
					Plastic	Paper	Other
Small Box (Current)	300 x 200 x 300	0.36 €/un	DS Smith	169	-	100%	-
Large Box (Current)	400 x 300 x 300	0.46 €/un	DS Smith	279	-	100%	-
Small Envelope (Current)	150 x 215 x 60	0.17 €/un	Ivo Pintado	10	20%	80%	-
Medium Envelope (Current)	230 x 340 x 65	0.28 €/un	Ivo Pintado	21	20%	80%	-
Large Envelope (Current)	300 x 445 x 70	0.42 €/un	Ivo Pintado	33	20%	80%	-
Small Mirror Box	780 x 580	5.02 €/un	Embalajes Capsa	1 043	-	100%	-
Medium Mirror Box	880 x 680	5.16 €/un	Embalajes Capsa	1 486	-	100%	-
Large Mirror Box	1080 x 780	5.64 €/un	Embalajes Capsa	1 595	-	100%	-
Tape	-	2.03 €/un	Ivo Pintado	108	100%	-	-
Stretch Film	-	9.20 €/roll	Ivo Pintado	570	100%	-	-
Bubble Wrap	-	38.75 €/roll	Ivo Pintado	32 000	100%	-	-
Filling paper	-	€43,11/uni	RajaPack	9 505	-	100%	-
Corrugated Carboard	-	32.72 €/roll	RajaPack	32 000	-	100%	-
Small Compostable Envelope	230 x 160 x 60	0.35 €/un	Noissue	6.25	70%	-	30%
Medium Compostable Envelope	385 x 260 x 65	0.50 €/un	Noissue	13.2	70%	-	30%
Large Compostable Envelope	420 x 300 x 70	0.55 €/un	Noissue	17.6	70%	-	30%
Small Reusable Envelope	250 x 350 x150	2.95 €/un	RePack	80	100%	-	-
Medium Reusable Envelope	330 x 600 x 160	3.55 €/un	RePack	116	100%	-	-
Large Reusable Envelope	350 x 680 x 220	3.95 €/un	RePack	177	100%	-	-
Small Reusable Box	210 x 150 x 80	2.85€/un	Hipli	63.5	100%	-	-
Medium Reusable Box	300 x 200 x 150	3.65€/un	Hipli	226.9	100%	-	-
Large Reusable Box	360 x 260 x 180	3.95 €/un	Hipli	424.8	100%	-	-
Kraft Tape	-	3.17 €/un	RajaPack	142.5	-	100%	-
Kraft Bubble	-	28.35 €/roll	RajaPack	2 500	-	100%	-

A.1.2. Packages Material Composition

Name	Material	Name	Material
Small Box (Current)	Cardboard	Corrugated Carboard	Cardboard
Large Box (Current)		Small Compostable Envelope	30% Corn Starch;15% PLA;65% PBAT
Small Envelope (Current)	5% LDPE;95% Paper	Medium Compostable Envelope	
Medium Envelope (Current)		Large Compostable Envelope	
Large Envelope (Current)		Small Reusable Envelope	Recycled PP
Small Mirror Box	Cardboard	Medium Reusable Envelope	
Medium Mirror Box		Large Reusable Envelope	
Large Mirror Box		Small Reusable Box	
Tape	PP	Medium Reusable Box	
Stretch Film	LLDPE*	Large Reusable Box	
Bubble Wrap	LDPE	Kraft Tape	Kraft Paper
Filling paper	Kraft Paper	Kraft Bubble	
Shipment Envelope	5% LDPE;95% Paper		

*Linear low density polyethylene

Appendix 2 – Green Dot Value

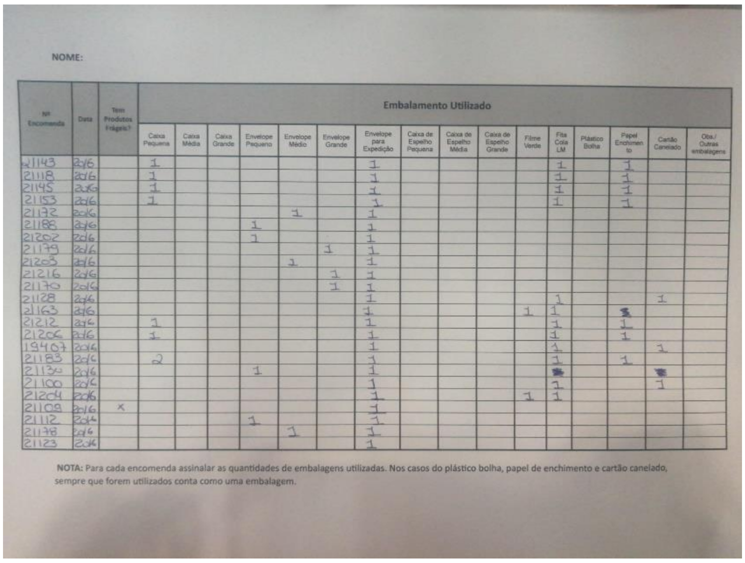
Packaging Material	€/kg
Glass	0.02040
Plastic	0.16160
Paper and Cardboard	0.10670
Carboard packages for liquid food	0.22450
Stell	0.15810
Aluminium	0.04050
Wood	0.05640
Other Materials	0.15490

Appendix 3 – Porto Alto Observations

A.3.1. Sample of Collected Observations Sheet

Order Number	Date	Fragile Products?	PACKAGING USED															
			Small Box	Medium Box	Large Box	Small Envelope	Medium Envelope	Large Envelope	Shipment Envelope	Small Mirror Box	Medium Mirror Box	Large Mirror Box	Stretch Film	Tape	Bubble Wrap	Filling Paper	Corrugated Cardboard	Other

Obs.: For each order, indicate the quantities of packaging used. In the case of bubble wrap, padding paper and corrugated cardboard, whenever they are used it counts as one usage .



NOME:

Nº Encomenda	Data	Tem Produtos Frágeis?	Embalamento Utilizado															
			Caixa Pequena	Caixa Média	Caixa Grande	Envelope Pequeno	Envelope Médio	Envelope Grande	Envelope para Expedição	Caixa de Espelho Pequena	Caixa de Espelho Média	Caixa de Espelho Grande	Filme Verde	Fita Cola LM	Plástico Bolha	Papel Enchimento	Cartão Canelado	Obs./ Outras embalagens
21143	20/6		1						1					1		1		
21118	20/6		1						1					1		1		
21145	20/6		1						1					1		1		
21153	20/6		1						1					1		1		
21172	20/6						1		1									
21188	20/6					1			1									
21202	20/6					1			1									
21179	20/6							1	1									
21203	20/6						1		1									
21216	20/6							1	1									
21170	20/6							1	1									
21128	20/6								1					1			1	
21163	20/6								1				1	1		[illegible]		
21212	20/6		1						1					1		1		
21206	20/6		1						1					1		1		
19407	20/6								1					1			1	
21183	20/6		2						1					1		1		
21130	20/6					1			1					[illegible]			[illegible]	
21100	20/6								1					1			1	
21204	20/6								1				1	1				
21109	20/6	x							1									
21112	20/6					1			1									
21178	20/6						1		1									
21123	20/6								1									

NOTA: Para cada encomenda assinalar as quantidades de embalagens utilizadas. Nos casos do plástico bolha, papel de enchimento e cartão canelado, sempre que forem utilizados conta como uma embalagem.

Image 1.Sample from the observations made. (20/06/2023)

Appendix 4 – Auxiliary Information

A.4.1. Packaging Costs

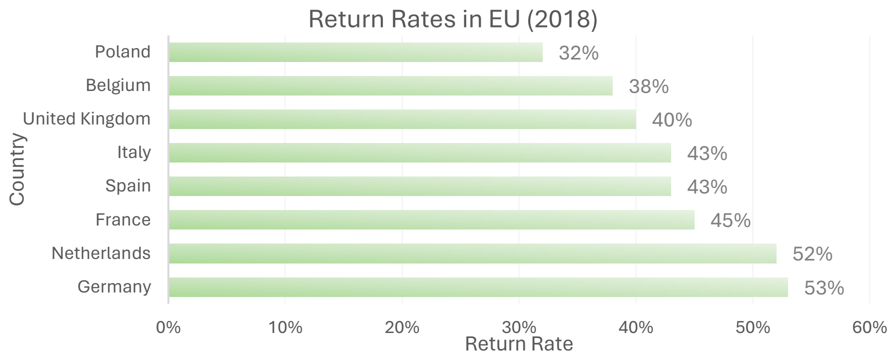
For each Scenario:

Small Envelope (1)	#Small Envelopes x €/un Small Envelope
Medium Envelope (2)	#Medium Envelopes x €/un Medium Envelope
Large Envelope (3)	#Large Envelopes x €/un Large Envelope
[A] TOTAL ENVELOPES	**(1) +(2) + (3)**
Small Box (4)	#Small Boxes x €/un Small Box
Medium Box (5)	#Medium Boxes x €/un Medium Box
Large Box (6)	#Large Box x €/un Large Box
Filling Material (7)	ρ Filling Material x €/dm^3
[B] TOTAL BOXES	**(4) + (5) + (6) + (7)**
Kraft Tape (8)	ρ Kraft Tape x €/dm^3
Kraft Bubble (9)	ρ Kraft Bubble x €/dm^3
Kraft Paper (10)	ρ Kraft Paper x €/dm^3
[C] TOTAL EXTERNAL PACKAGING	**(8) + (9) + (10)**
[D] Green Dot Value (11)	**Weight Plastic x Plastic GDV + Weight Paper x Paper GDV**
TOTAL PACKAGING COSTS	**[A] + [B] + [C] +[D]**

For reusable packages, in (1), (2), (3), (4), (5) and (6), the value obtained was divided by the reuse cycles and return rates:

$$\frac{\text{Total Cost of Reusable Packages}}{\text{Return Rate } \times \text{Reuse Cycles}}$$

A.4.2. Return Rates Across Europe (Statista,2019)



Appendix 5 – Life Cycle Assessment

A.5.1. Life Cycle Inventory

Baseline

Package/Process	FU Quantity	SimaPro References	Unit
Stretch Film	6.19	Polyethylene, low density, granulate {GLO}| Production | Cut-off, U	kg
Boxes	666.30	Folding boxboard/chipboard {GLO}| Production | Cut-off, U	Kg
Envelopes	55.72 2.93	Polyethylene, low density, granulate {GLO}| Production r | Cut-off, U Kraft paper, unbleached {GLO}| Production | Cut-off, U	Kg
Filling Material	265.07	Kraft paper, unbleached {GLO}| Production | Cut-off, U	Kg
Tape	6.06	Polypropylene, granulate {GLO}| Production | Cut-off, U	kg
Bubble Wrap	1.37	Polyethylene, low density, granulate {GLO}| Production | Cut-off, U	Kg
Corrugated Cardboard	48.89	Corrugated board box {RER}| Production corrugated board box | Cut-off, U	Kg
Electricity	40.96	Electricity, medium voltage {PT}| market for | Cut-off, U	kJ
Transportation	182.70	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U	tkm

Scenario 1

Material	FU Quantity	SimaPro References	Unit
Boxes	20.38	Folding boxboard/chipboard {GLO}| Production | Cut-off, U	Kg
Envelopes	7.11 16.59	Sweet corn {GLO}| Production sweet corn | Cut-off, U Polylactide, granulate {GLO}| Production | Cut-off, U	Kg
Kraft Paper	156.68	Kraft paper, unbleached {GLO}| Production | Cut-off, U	Kg
Kraft Tape	11.26	Kraft paper, unbleached {GLO}| Production | Cut-off, U	Kg
Electricity	14.69	Electricity, medium voltage {PT}| Production | Cut-off, U	KJ
Transportation	14.80 50.25	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U Transport, freight, aircraft, medium haul {GLO}| market for transport, freight, aircraft, medium haul | Cut-off, U	tkm

Scenario 2

Material	FU Quantity	SimaPro References	Unit
Boxes	0.0	Polyethylene, high density, granulate, recycled {Europe without Switzerland} | Production polyethylene, high density, granulate, recycled | Cut-off, U	Kg
Envelopes	90.9	Polyethylene, high density, granulate, recycled {Europe without Switzerland} | Production polyethylene, high density, granulate, recycled | Cut-off, U	Kg
Kraft Paper	136.3	Kraft paper, unbleached {GLO}| Production | Cut-off, U	Kg
Kraft Tape	7.5	Kraft paper, unbleached {GLO}| Production | Cut-off, U	Kg
Cleaning	41.26 1.65	Water, completely softened {RER}| Production water, completely softened | Cut-off, U Soap {GLO}| Production | Cut-off, U	Kg
Electricity	54.86	Electricity, medium voltage {PT}| market for | Cut-off, U	KJ
Transportation	34.7 54.54	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U Transport, freight, aircraft, medium haul {GLO}| market for transport, freight, aircraft, medium haul | Cut-off, U	tkm

Scenario 3

Material	FU Quantity	SimaPro References	Unit
Boxes	6.5	Folding boxboard/chipboard {GLO}| Production | Cut-off, U	Kg
Envelopes	7.11 16.59	Sweet corn {GLO}| Production sweet corn | Cut-off, U Polylactide, granulate {GLO}| Production | Cut-off, U	Kg
Kraft Paper	157.78	Kraft paper, unbleached {GLO}| Production | Cut-off, U	Kg
Kraft Tape	11.0	Kraft paper, unbleached {GLO}| Production | Cut-off, U	Kg
Cleaning	14.2 56.88	Water, completely softened {RER}| market for water, completely softened | Cut-off, U Soap {GLO}| market for | Cut-off, U	Kg g
Electricity	18.55	Electricity, medium voltage {PT}| market for | Cut-off, U	kJ
Transportation	53.68 7.91	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U Transport, freight, aircraft, medium haul {GLO}| market for transport, freight, aircraft, medium haul | Cut-off, U	tkm

Scenario 4

Material	FU Quantity	SimaPro References	Unit
Boxes	945.07	Folding boxboard/chipboard {GLO}| Production | Cut-off, U	Kg
Kraft Paper	5.62	Kraft paper, unbleached {GLO}| Production | Cut-off, U	Kg
Electricity	570.41	Electricity, medium voltage {PT}| market for | Cut-off, U	kJ
Transportation	56.09	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U	tkm

A.5.2. ReCiPe Results

Baseline - Characterization

Impact Category	Unit	Bubble Wrap	Boxes	Corrugated Cardboard	Envelopes	Filling Material	Stretch Film	Tape	TOTAL
FF	kg PM2.5 eq	2.67E-03	1.53E+00	5.98E-02	1.06E-01	3.97E-01	1.10E-02	1.01E-02	2.12E+00
FS	kg oil eq	2.17E+00	2.52E+02	1.33E+01	1.65E+01	5.11E+01	9.62E+00	9.80E+00	3.54E+02
FE	kg 1,4-DCB	2.70E-01	3.50E+01	2.35E+00	2.63E+00	1.16E+01	1.20E+00	1.01E+00	5.40E+01
FEU	kg P eq	6.92E-04	4.74E-01	2.21E-02	3.62E-02	1.58E-01	1.93E-03	1.63E-03	6.94E-01
GW	kg CO_2 eq	3.75E+00	1.20E+03	6.63E+01	5.14E+01	2.64E+02	1.65E+01	1.55E+01	1.62E+03
HT	kg 1,4-DCB	8.00E-02	3.70E+01	1.42E+00	2.26E+00	9.09E+00	3.06E-01	2.75E-01	5.04E+01
HNT	kg 1,4-DCB	4.08E+00	1.20E+03	5.55E+01	1.07E+02	5.42E+02	1.72E+01	1.45E+01	1.94E+03
IR	kBq Co-60 eq	2.94E-01	1.62E+02	4.20E+00	1.24E+01	5.36E+01	6.27E-01	5.67E-01	2.34E+02
LU	m2a crop eq	3.36E-02	9.23E+02	1.93E+01	1.14E+02	2.91E+02	1.13E-01	9.71E-02	1.35E+03
ME	kg 1,4-DCB	3.71E-01	4.65E+01	3.08E+00	3.62E+00	1.59E+01	1.64E+00	1.38E+00	7.24E+01
MEU	kg N eq	3.09E-04	1.84E-01	1.83E-02	5.53E-03	8.71E-02	1.23E-03	1.05E-03	2.97E-01
MS	kg Cu eq	5.60E-03	2.04E+00	1.26E-01	1.67E-01	6.19E-01	2.96E-02	2.80E-02	3.01E+00
OFH	kg NOx eq	6.09E-03	2.30E+00	1.28E-01	1.84E-01	6.18E-01	2.36E-02	2.15E-02	3.29E+00
OFT	kg NOx eq	6.90E-03	2.35E+00	1.30E-01	1.90E-01	6.31E-01	2.56E-02	2.33E-02	3.36E+00
SO	kg CFC11 eq	4.97E-07	5.81E-04	5.28E-05	6.73E-05	3.25E-04	2.46E-06	1.36E-06	1.03E-03
TA	kg SO2 eq	7.37E-03	4.21E+00	1.51E-01	2.37E-01	9.16E-01	3.04E-02	2.87E-02	5.58E+00
TE	kg 1,4-DCB	7.41E+00	2.42E+03	1.67E+02	2.89E+02	1.16E+03	3.51E+01	2.94E+01	4.11E+03
WC	m3	4.62E-02	2.19E+01	6.29E-01	3.13E+00	1.12E+01	2.89E-01	1.27E-01	3.73E+01

Baseline – Normalization

Impact Category	Bubble Wrap	Boxes	Corrugated Cardboard	Envelopes	Filling Material	Stretch Film	Tape	TOTAL
FF	1.04E-04	5.98E-02	2.34E-03	4.15E-03	1.55E-02	4.32E-04	3.95E-04	1.04E-04
FS	2.21E-03	2.57E-01	1.35E-02	1.69E-02	5.22E-02	9.81E-03	1.00E-02	2.21E-03
FE	2.20E-01	2.85E+01	1.91E+00	2.14E+00	9.42E+00	9.74E-01	8.22E-01	2.20E-01
FEU	1.07E-03	7.30E-01	3.41E-02	5.58E-02	2.43E-01	2.97E-03	2.51E-03	1.07E-03
GW	4.70E-04	1.50E-01	8.31E-03	6.44E-03	3.30E-02	2.07E-03	1.94E-03	4.70E-04
HT	2.89E-02	1.34E+01	5.13E-01	8.15E-01	3.28E+00	1.10E-01	9.92E-02	2.89E-02
HNT	2.74E-02	8.05E+00	3.72E-01	7.20E-01	3.63E+00	1.16E-01	9.73E-02	2.74E-02
IR	6.12E-04	3.37E-01	8.74E-03	2.57E-02	1.11E-01	1.30E-03	1.18E-03	6.12E-04
LU	5.44E-06	1.50E-01	3.12E-03	1.85E-02	4.72E-02	1.83E-05	1.57E-05	5.44E-06
ME	3.59E-01	4.50E+01	2.98E+00	3.51E+00	1.54E+01	1.59E+00	1.34E+00	3.59E-01
MEU	6.70E-05	3.99E-02	3.96E-03	1.20E-03	1.89E-02	2.67E-04	2.27E-04	6.70E-05
MS	4.66E-08	1.70E-05	1.05E-06	1.39E-06	5.15E-06	2.46E-07	2.33E-07	4.66E-08
OFH	2.96E-04	1.12E-01	6.21E-03	8.96E-03	3.00E-02	1.15E-03	1.05E-03	2.96E-04
OFT	3.88E-04	1.32E-01	7.34E-03	1.07E-02	3.55E-02	1.44E-03	1.31E-03	3.88E-04
SO	8.30E-06	9.70E-03	8.82E-04	1.12E-03	5.43E-03	4.11E-05	2.27E-05	8.30E-06
TA	1.80E-04	1.03E-01	3.68E-03	5.79E-03	2.23E-02	7.41E-04	7.01E-04	1.80E-04
TE	7.15E-03	2.34E+00	1.61E-01	2.79E-01	1.12E+00	3.38E-02	2.84E-02	7.15E-03
WC	1.73E-04	8.23E-02	2.36E-03	1.18E-02	4.18E-02	1.08E-03	4.74E-04	1.73E-04

Baseline – Single Score

Damage Category	Unit	Bubble Wrap	Boxes	Corrugated Cardboard	Envelopes	Filling Material	Stretch Film	Tape	TOTAL
Human health	Pt	0.11	42.17	1.98	2.58	11.28	0.48	0.43	59.03
Ecosystems	Pt	0.01	7.42	0.24	0.73	2.15	0.04	0.03	10.62
Resources	Pt	0.01	0.47	0.03	0.04	0.10	0.03	0.03	0.71

Scenario 1 - Characterization

Impact Category	Unit	Boxes	Envelopes	Kraft Paper/Kraft Bubble	Tape	TOTAL
FF	kg PM2.5 eq	4.68E-02	1.18E-01	2.35E-01	1.69E-02	4.17E-01
FS	kg oil eq	7.70E+00	2.08E+01	3.02E+01	2.17E+00	6.09E+01
FE	kg 1,4-DCB	1.07E+00	3.21E+00	6.83E+00	4.91E-01	1.16E+01
FEU	kg P eq	1.45E-02	2.11E-02	9.33E-02	6.71E-03	1.36E-01
GW	kg CO_2 eq	3.67E+01	7.62E+01	1.56E+02	1.12E+01	2.80E+02
HT	kg 1,4-DCB	1.13E+00	1.70E+00	5.38E+00	3.86E-01	8.59E+00
HNT	kg 1,4-DCB	3.67E+01	5.09E+01	3.20E+02	2.30E+01	4.31E+02
IR	kBq Co-60 eq	4.96E+00	3.48E+00	3.17E+01	2.28E+00	4.24E+01
LU	m2a crop eq	2.82E+01	1.08E+01	1.72E+02	1.24E+01	2.24E+02
ME	kg 1,4-DCB	1.42E+00	3.95E+00	9.39E+00	6.75E-01	1.54E+01
MEU	kg N eq	5.62E-03	2.72E-02	5.15E-02	3.70E-03	8.80E-02
MS	kg Cu eq	6.23E-02	1.82E-01	3.66E-01	2.63E-02	6.36E-01
OFH	kg NOx eq	7.05E-02	2.39E-01	3.65E-01	2.62E-02	7.01E-01
OFT	kg NOx eq	7.19E-02	2.47E-01	3.73E-01	2.68E-02	7.18E-01
SO	kg CFC11 eq	1.78E-05	2.58E-04	1.92E-04	1.38E-05	4.82E-04
TA	kg SO2 eq	1.29E-01	3.27E-01	5.41E-01	3.89E-02	1.04E+00
TE	kg 1,4-DCB	7.42E+01	1.81E+02	6.85E+02	4.92E+01	9.89E+02
WC	m3	6.71E-01	2.46E+00	6.59E+00	4.74E-01	1.02E+01

Scenario 1 - Normalization

Impact Category	Boxes	Envelopes	Kraft Paper/Kraft Bubble	Tape	TOTAL
FF	1.83E-03	4.63E-03	9.17E-03	6.59E-04	1.63E-02
FS	7.85E-03	2.13E-02	3.08E-02	2.22E-03	6.22E-02
FE	8.72E-01	2.61E+00	5.57E+00	4.00E-01	9.45E+00
FEU	2.23E-02	3.24E-02	1.44E-01	1.03E-02	2.09E-01
GW	4.59E-03	9.54E-03	1.95E-02	1.40E-03	3.51E-02
HT	4.09E-01	6.13E-01	1.94E+00	1.39E-01	3.10E+00
HNT	2.46E-01	3.41E-01	2.15E+00	1.54E-01	2.89E+00
IR	1.03E-02	7.24E-03	6.59E-02	4.73E-03	8.81E-02
LU	4.57E-03	1.74E-03	2.79E-02	2.01E-03	3.62E-02
ME	1.38E+00	3.82E+00	9.10E+00	6.54E-01	1.50E+01
MEU	1.22E-03	5.90E-03	1.12E-02	8.03E-04	1.91E-02
MS	5.19E-07	1.52E-06	3.05E-06	2.19E-07	5.30E-06
OFH	3.43E-03	1.16E-02	1.77E-02	1.28E-03	3.41E-02
OFT	4.05E-03	1.39E-02	2.10E-02	1.51E-03	4.04E-02
SO	2.97E-04	4.32E-03	3.21E-03	2.31E-04	8.06E-03
TA	3.14E-03	7.97E-03	1.32E-02	9.49E-04	2.53E-02
TE	7.16E-02	1.74E-01	6.61E-01	4.75E-02	9.54E-01
WC	2.52E-03	9.21E-03	2.47E-02	1.78E-03	3.82E-02

Scenario 1 – Single Score

Impact Category	Unit	Boxes	Envelopes	Kraft Paper/Kraft Bubble	Tape	TOTAL
Human health	Pt	1.29	2.76	6.67	0.48	11.20
Ecosystems	Pt	0.23	0.24	1.27	0.09	1.83
Resources	Pt	0.01	0.05	0.06	0.00	0.13

Scenario 2 – Characterization

Impact Category	Unit	Envelopes	Kraft Paper/Kraft Bubble	Kraft Tape	TOTAL
FF	kg PM2.5 eq	2.62E-01	2.07E-01	1.12E-02	4.80E-01
FS	kg oil eq	7.40E+01	2.74E+01	1.45E+00	1.03E+02
FE	kg 1,4-DCB	2.03E+01	6.08E+00	3.27E-01	2.67E+01
FEU	kg P eq	5.87E-02	8.15E-02	4.47E-03	1.45E-01
GW	kg CO_2 eq	3.15E+02	1.39E+02	7.46E+00	4.62E+02
HT	kg 1,4-DCB	5.53E+00	4.79E+00	2.57E-01	1.06E+01
HNT	kg 1,4-DCB	3.40E+02	2.82E+02	1.53E+01	6.38E+02
IR	kBq Co-60 eq	1.31E+01	2.77E+01	1.52E+00	4.23E+01
LU	m2a crop eq	8.98E+00	1.50E+02	8.24E+00	1.67E+02
ME	kg 1,4-DCB	2.81E+01	8.37E+00	4.49E-01	3.69E+01
MEU	kg N eq	4.34E-02	4.48E-02	2.47E-03	9.07E-02
MS	kg Cu eq	4.14E-01	3.43E-01	1.75E-02	7.74E-01
OFH	kg NOx eq	9.79E-01	3.22E-01	1.75E-02	1.32E+00
OFT	kg NOx eq	9.92E-01	3.29E-01	1.79E-02	1.34E+00
SO	kg CFC11 eq	1.11E-04	1.69E-04	9.21E-06	2.90E-04
TA	kg SO2 eq	7.05E-01	4.78E-01	2.59E-02	1.21E+00
TE	kg 1,4-DCB	9.47E+02	6.26E+02	3.28E+01	1.61E+03
WC	m3	1.24E+00	5.74E+00	3.16E-01	7.29E+00

Scenario 2 – Normalization

Impact Category	Envelopes	Kraft Paper/Kraft Bubble	Kraft Tape	TOTAL
FF	1.02E-02	8.09E-03	4.39E-04	1.88E-02
FS	7.54E-02	2.80E-02	1.48E-03	1.05E-01
FE	1.65E+01	4.96E+00	2.66E-01	2.18E+01
FEU	9.05E-02	1.26E-01	6.88E-03	2.23E-01
GW	3.94E-02	1.74E-02	9.34E-04	5.78E-02
HT	2.00E+00	1.73E+00	9.29E-02	3.82E+00
HNT	2.28E+00	1.89E+00	1.03E-01	4.28E+00
IR	2.73E-02	5.75E-02	3.15E-03	8.79E-02
LU	1.46E-03	2.43E-02	1.34E-03	2.71E-02
ME	2.72E+01	8.11E+00	4.35E-01	3.57E+01
MEU	9.41E-03	9.73E-03	5.35E-04	1.97E-02
MS	3.44E-06	2.85E-06	1.46E-07	6.44E-06
OFH	4.76E-02	1.57E-02	8.49E-04	6.41E-02
OFT	5.59E-02	1.85E-02	1.01E-03	7.54E-02
SO	1.85E-03	2.83E-03	1.54E-04	4.83E-03
TA	1.72E-02	1.17E-02	6.32E-04	2.95E-02
TE	9.14E-01	6.04E-01	3.16E-02	1.55E+00
WC	4.63E-03	2.15E-02	1.18E-03	2.73E-02

Scenario 2 – Single Score

Impact Category	Unit	Boxes	Envelopes	Kraft Paper/Kraft Bubble	Kraft Tape	TOTAL
Human health	Pt	0.00	9.13	5.91	0.32	15.36
Ecosystems	Pt	0.00	0.70	1.11	0.06	1.87
Resources	Pt	0.00	0.22	0.06	0.00	0.28

Scenario 3- Characterization

Impact Category	Unit	Boxes	Envelopes	Kraft Paper/Kraft Bubble	Tape	TOTAL
FF	kg PM2.5 eq	1.13E-02	1.15E-01	1.63E-01	1.64E-02	3.06E-01
FS	kg oil eq	2.87E+00	1.97E+01	2.10E+01	2.12E+00	4.57E+01
FE	kg 1,4-DCB	1.41E+00	3.19E+00	4.75E+00	4.79E-01	9.82E+00
FEU	kg P eq	3.00E-03	2.10E-02	6.48E-02	6.54E-03	9.54E-02
GW	kg CO_2 eq	1.48E+01	7.26E+01	1.08E+02	1.09E+01	2.07E+02
HT	kg 1,4-DCB	3.70E-01	1.69E+00	3.73E+00	3.77E-01	6.17E+00
HNT	kg 1,4-DCB	2.25E+01	5.01E+01	2.22E+02	2.24E+01	3.17E+02
IR	kBq Co-60 eq	8.61E-01	3.44E+00	2.20E+01	2.22E+00	2.85E+01
LU	m2a crop eq	4.22E-01	1.08E+01	1.20E+02	1.21E+01	1.43E+02
ME	kg 1,4-DCB	1.95E+00	3.92E+00	6.52E+00	6.58E-01	1.30E+01
MEU	kg N eq	2.56E-03	2.72E-02	3.58E-02	3.61E-03	6.91E-02
MS	kg Cu eq	2.69E-02	1.81E-01	2.54E-01	2.56E-02	4.87E-01
OFH	kg NOx eq	3.65E-02	2.23E-01	2.54E-01	2.56E-02	5.38E-01
OFT	kg NOx eq	3.71E-02	2.30E-01	2.59E-01	2.61E-02	5.52E-01
SO	kg CFC11 eq	5.08E-06	2.58E-04	1.34E-04	1.35E-05	4.10E-04
TA	kg SO2 eq	2.87E-02	3.16E-01	3.76E-01	3.79E-02	7.59E-01
TE	kg 1,4-DCB	5.74E+01	1.75E+02	4.76E+02	4.80E+01	7.56E+02
WC	m3	6.36E-02	2.45E+00	4.58E+00	4.62E-01	7.56E+00

Scenario 3 - Normalization

Impact Category	Boxes	Envelopes	Kraft Paper/Kraft Bubble	Tape	TOTAL
FF	4.42E-04	4.50E-03	6.37E-03	6.43E-04	1.20E-02
FS	2.93E-03	2.01E-02	2.14E-02	2.16E-03	4.66E-02
FE	1.15E+00	2.60E+00	3.87E+00	3.90E-01	8.01E+00
FEU	4.63E-03	3.23E-02	9.98E-02	1.01E-02	1.47E-01
GW	1.85E-03	9.10E-03	1.36E-02	1.37E-03	2.59E-02
HT	1.33E-01	6.09E-01	1.35E+00	1.36E-01	2.23E+00
HNT	1.51E-01	3.36E-01	1.49E+00	1.51E-01	2.13E+00
IR	1.79E-03	7.16E-03	4.58E-02	4.62E-03	5.93E-02
LU	6.83E-05	1.74E-03	1.94E-02	1.96E-03	2.31E-02
ME	1.89E+00	3.80E+00	6.32E+00	6.37E-01	1.26E+01
MEU	5.56E-04	5.90E-03	7.76E-03	7.83E-04	1.50E-02
MS	2.24E-07	1.51E-06	2.12E-06	2.13E-07	4.06E-06
OFH	1.77E-03	1.08E-02	1.23E-02	1.24E-03	2.62E-02
OFT	2.09E-03	1.29E-02	1.46E-02	1.47E-03	3.11E-02
SO	8.49E-05	4.30E-03	2.23E-03	2.25E-04	6.84E-03
TA	7.01E-04	7.72E-03	9.18E-03	9.26E-04	1.85E-02
TE	5.54E-02	1.68E-01	4.59E-01	4.63E-02	7.29E-01
WC	2.39E-04	9.20E-03	1.72E-02	1.73E-03	2.83E-02

Scenario 3 – Single Score

Impact Category	Unit	Boxes	Envelopes	Kraft Paper/Kraft Bubble	Tape	TOTAL
Human health	Pt	0.46	2.66	6.72	0.47	10.31
Ecosystems	Pt	0.03	0.24	1.28	0.09	1.64
Resources	Pt	0.01	0.05	0.06	0.00	0.12

Scenario 4- Characterization

Impact Category	Unit	Boxes	Corrugated Cardboard	TOTAL
FF	kg PM2.5 eq	1.16E+00	8.42E-03	1.17E+00
FS	kg oil eq	2.58E+02	1.08E+00	2.59E+02
FE	kg 1,4-DCB	4.55E+01	2.45E-01	4.57E+01
FEU	kg P eq	4.29E-01	3.35E-03	4.32E-01
GW	kg CO_2 eq	1.29E+03	5.59E+00	1.29E+03
HT	kg 1,4-DCB	2.76E+01	1.93E-01	2.77E+01
HNT	kg 1,4-DCB	1.08E+03	1.15E+01	1.09E+03
IR	kBq Co-60 eq	8.13E+01	1.14E+00	8.25E+01
LU	m2a crop eq	3.73E+02	6.18E+00	3.79E+02
ME	kg 1,4-DCB	5.96E+01	3.37E-01	6.00E+01
MEU	kg N eq	3.53E-01	1.85E-03	3.55E-01
MS	kg Cu eq	2.45E+00	1.31E-02	2.47E+00
OFH	kg NOx eq	2.47E+00	1.31E-02	2.49E+00
OFT	kg NOx eq	2.53E+00	1.34E-02	2.54E+00
SO	kg CFC11 eq	1.02E-03	6.90E-06	1.03E-03
TA	kg SO2 eq	2.92E+00	1.94E-02	2.94E+00
TE	kg 1,4-DCB	3.28E+03	2.46E+01	3.30E+03
WC	m3	1.22E+01	2.36E-01	1.24E+01

Scenario 4- Normalization

Impact Category	Boxes	Corrugated Cardboard	TOTAL
FF	4.53E-02	3.29E-04	4.56E-02
FS	2.63E-01	1.11E-03	2.64E-01
FE	3.71E+01	2.00E-01	3.73E+01
FEU	6.60E-01	5.15E-03	6.65E-01
GW	1.61E-01	7.00E-04	1.62E-01
HT	9.95E+00	6.96E-02	1.00E+01
HNT	7.22E+00	7.71E-02	7.29E+00
IR	1.69E-01	2.36E-03	1.72E-01
LU	6.04E-02	1.00E-03	6.14E-02
ME	5.78E+01	3.26E-01	5.81E+01
MEU	7.66E-02	4.01E-04	7.70E-02
MS	2.04E-05	1.09E-07	2.06E-05
OFH	1.20E-01	6.36E-04	1.21E-01
OFT	1.42E-01	7.53E-04	1.43E-01
SO	1.71E-02	1.15E-04	1.72E-02
TA	7.13E-02	4.74E-04	7.17E-02
TE	3.16E+00	2.37E-02	3.18E+00
WC	4.56E-02	8.87E-04	4.65E-02

Scenario 4- Single Score

Impact Category	Unit	Boxes	Corrugated Cardboard	TOTAL
Ecosystems	Pt	38.30	0.24	38.54
Resources	Pt	4.63	0.05	4.68
Human health	Pt	0.60	0.00	0.60