Louvain School of Management and Instituto Superior Técnico

Logistic Network Design and Planning for a Glass Deposit-Refund System

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Abstract

Over the last few years, waste generation has been increasing, and consequently, organisations have been defining policies to dimmish such trends. The European Union (EU) set a minimum recycling or reuse rate of 70% by 2025 for glass packaging waste. However, several countries are still under this target, including Portugal. The current national glass packaging waste system efficiency was 56% of recycling in 2020, far from the EU's objectives. This led to the decision of studying the implementation of a beverage packaging Deposit-Refund System (DRS) in Portugal.

In this way, this work aims to design and plan the DRS logistics network for Portugal with a focus on glass beverage containers. An extensive study of the DRS characteristics was made. The conceptual scheme was analysed, and DRS in other countries was studied. In addition, a literature review of the DRS topic was made. One key conclusion was that there is no literature concerning strategic network design models for DRS, which makes this work particularly relevant.

A generic MILP, single-objective, cost-minimization formulation is developed to fulfil this research gap. The decisions concern facilities positioning, flow allocation, and high-level inventory planning.

An application to the Portuguese case was made and validated with real data. The cost of the system in a five-year horizon would be around 66 million euros of which 14 million are fixed costs. The results of this work aimed at helping decision-makers to support better decisions regarding the DRS. However, limitations to the study were identified, which leads to future research development.

Keywords: Deposit-Refund System; Strategic Network Design; Glass Packaging Waste; Waste Management; Reverse Logistics

Resumo

Nos últimos anos, a produção de resíduos tem vindo a aumentar e, consequentemente, organizações têm vindo a definir políticas para diminuir essas tendências. A União Europeia (UE) estabeleceu uma taxa mínima de reciclagem ou reutilização de 70% até 2025 para resíduos de embalagens de vidro. No entanto, vários países encontram-se abaixo deste objetivo, incluindo Portugal. O desempenho do atual sistema de resíduos de embalagens de vidro foi 56% de reciclagem em 2020, distante das metas da UE. Isto levou à decisão de estudar a implementação do Sistema de Depósito-Reembolso (SDR) para embalagens de vidro em Portugal.

Desta forma, este trabalho visa desenhar e planear uma rede logística do DRS para Portugal, com enfoque nas garrafas de vidro. Foi realizado um estudo extensivo das características do DRS. O esquema conceptual foi analisado, e o DRS noutros países foi estudado. Para além disso, foi elaborada uma revisão bibliográfica sobre o DRS. Uma conclusão chave é o facto de não existir literatura sobre modelos de planeamento logístico estratégico para DRS, o que torna este trabalho particularmente relevante.

Foi desenvolvida uma formulação genérica de MILP, de único objetivo e minimização de custos para preencher esta lacuna na bibliografia. As decisões são o posicionamento das instalações, alocação de fluxos e planeamento de inventário de alto-nível.

Foi feita uma aplicação a Portugal, validada com dados reais. O custo do sistema, num horizonte de cinco anos, será cerca de 66 milhões de euros, dos quais 14 milhões são custos fixos. Os resultados deste trabalho visam ajudar decisores a tomarem melhores decisões em relação ao DRS. No entanto, foram identificadas limitações, o que leva ao desenvolvimento futuro deste tópico.

Palavras-chave: Sistema de Deposito-Reembolso; Desenho Estratégico de Rede; Resíduos de Embalagem de Vidro; Gestão de Resíduos; Logística Inversa

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Acronyms

APA	Agência Portuguesa do Ambiente
CEAP	Circular Economy Action Plan
DRS	Deposit Refund System
EU	European Union
EPR	Extended Producer Responsibility
HORECA	Hotels, Restaurants and Cafés
MSW	Municipal Solid Waste
RHF	Retail Handling Fee
RVM	Reverse Vending Machine
SIGRE	Sistema Integrado de Gestão de Residuos de Embalagens
WEEE	Waste from Electrical and Electronic Equipment

Chapter 1 - Introduction

This Chapter has the goal of introducing the work developed. Section 1.1. starts by presenting the background context and motivation for the research topic. Section 1.2. then shows the main four research objectives that this work aims to fulfil. Section 1.3. delivers the research methodology needed to give an answer to the objectives defined. Finally, this Chapter is concluded by section 1.4. which presents the document structure.

1.1 Background And Motivation

Over the years, the topic of waste management and climate change has been in the spotlight and it is considered to be one of the many challenges that future generations will have to face. The old mindset of simply consuming and disposing of waste has been questioned several times because it turned out to be unsustainable. This old overconsumption trend is unlikely to change in the next years therefore, solutions to change processes and consumption towards sustainability are forcing supply chains to readapt themselves to what people are claiming nowadays – a way of reducing or at least extending the life cycle of products included in sustainable supply chains. In the case of beverage packaging waste, legislation and collection targets have been established at country and international levels. These targets are becoming stricter over the years which is the case of household packaging waste.

Packaging waste can be seen as a type of waste where there are a lot of opportunities to improve, for example, the recycling efficiency, or through new approaches to implement. Currently, several countries in Europe, including Portugal, are far from achieving the waste recycling targets for glass packaging waste which defines the 2025 target of a 70% rate of recycling or reuse (REA | APA, 2021). To be able to meet the European Union (EU) imposed targets, countries have been searching for new methods or incentives to improve the beverage waste management system. In the case of Portugal, decision-makers considered implementing a Deposit Refund System (DRS) for beverage packaging (3Drivers & NOWA, 2020).

The DRS is a waste management system that aims at creating incentives for consumers to return the beverage packaging after consumption. It generally works with a deposit fee that the consumer pays when buying the product which then is returned back when delivering the packaging again. This scheme can be a way of increasing recycling rates and also obtaining an end-product with a higher degree of purity for recycling to be more effective. The current Portuguese waste management system for packaging is composed of street deposits and door-to-door collections only achieving recycling rates of 56% (REA | APA, 2021). The need to increase the recycling rate justifies the implementation of the DRS in order to solve this issue.

Since this system is planned to be implemented in the near future, the need to study deeply the Portuguese case is an advantage. This system carries costs and logistics planning at different levels. The study of the DRS scheme and its application to the Portuguese case can be beneficial indeed. It can reduce costs through a good strategic design and planning of this reverse logistics network. Next, the clear research objectives will be explained.

1.2 Research Objectives

The research objectives are important to be clearly defined since they will drive the work development. Taking into account the background described in the previous section, four main objectives were found:

- The complete description and characterization of the DRS including logistics, working methods, costs and incomes. To complete this characterization, several DRS will be benchmarked;
- To develop an optimisation model to support the for the design and planning of a strategic network of the DRS;
- Apply the model developed to the Portuguese context.

In the next section, the research methodology will be introduced.

1.3 Research Methodologies

In order to answer the research objectives in the correct manner, a methodology is needed to structure the pathway there. The research methodology involved in five steps that are described below:

1. Problem definition and contextualization: In this first step, the purpose is to analyse the waste panorama and then focus on the glass packaging waste. Then, the DRS will be analysed given a context.
2. Literature review: This step is considered a critical one. Two main sets of literature were analysed. The first focuses on the DRS literature in order to obtain comprehensive and state-of-the-art information on this topic. The second focuses on waste management network design models to understand what methods have been used to address the problem in the study.
3. Model formulation development: In this step, taking into account the insights developed in steps one and two, a mathematical formulation was developed for the design and planning of a DSR system.
4. Data sourcing and model validation: In order to validate the model, data inputs are needed. For this, several data sources and estimation methods were used. Then, taking real data into account, the model was implemented to the Portugues DSR context.
5. Results analysis: This last step focuses on analysing the results and deeply understanding how real data parameters and variables will react. Conclusions were made concerning the implementation of a DRS for glass beverage waste in Portugal.

1.4 Document Structure

In this last section, the document structure is presented.

Chapter 1 – Introduction: In this Chapter, the main motivations and context that led to this work's development are shown. In addition, the objectives and the research methods are described;

Chapter 2 – Contextualization and problem description: This Chapter starts by depicting the waste management panorama in Europe and in Portugal. Then, the DRS is introduced and benchmarked. In addition, the legal framework for packaging waste management is analysed. In the end, some limitations of DRS schemes are enumerated;

Chapter 3 – Literature Review: The literature review in this Chapter focuses on two topics. First, an analysis of the DRS related literature is made. Then some reverse logistics for waste management network design models are analysed.

Chapter 4 – Model design: In this Chapter, a detailed DRS logistics characterization is made. Then, the mathematical formulation is developed.

Chapter 5 – Data treatment: In this Chapter, all the data inputs needed for the model are calculated. Some estimations are made. Moreover, the potential locations sets for the facilities are chosen.

Chapter 6 – Results Analysis: The model, in this Chapter, will be subjected to a scenario and sensibility analysis. Conclusions concerning the critical parameters and variables are taken.

Chapter 7 – Conclusions: In the final Chapter, the main conclusions and limitations throughout the work will be presented. Furthermore, future work to be developed will be described.

Chapter 2 – Contextualization and Problem Description

In this Chapter, the contextualization of this work is presented. Section 2.1 starts by presenting data regarding packaging waste for the EU and Portugal. Then, section 2.2 will describe the regulations and incentives that are currently in place or previous legislation that is relevant to be mentioned. Section 2.3 will introduce the DRS and compare the different schemes implemented in other countries. Section 2.4. will discuss the negative impacts and incentives that these types of systems can have on waste management. Finally, this Chapter is closed by section 2.5. which sets the challenge to be solved in this work.

2.1 Circular Economy Prospects for Glass Beverage Packaging

The world is shifting toward circular supply chains that promote the extension of the product's life cycle. In the case of the glass packaging industry, there is an opportunity to avoid landfilling and increase recycling. In this subsection, that opportunity is going to be analysed by presenting facts and figures regarding the current packaging waste panorama and, more precisely, the glass packaging. In addition, the Portuguese current packaging waste management system is going to be analysed and market figures will be given.

2.1.1 Packaging Waste

According to Article 3 of the EU packaging directive, "Packaging is defined as any material that is used to contain, protect, handle, deliver or present goods. Packaging waste can arise from a wide range of sources including supermarkets, Retail outlets, manufacturing industries, households, hotels, hospitals, restaurants and transport companies. Items like glass bottles, plastic containers, aluminium cans, food wrappers, timber pallets and drums are all classified as packaging." (EUR-Lex, 2018)

There is a rising concern regarding consumer packaging waste generation. This waste is significant and its end-of-life treatment needs to be taken into consideration. In general, the packaging waste generated by consumers has been growing in the past years. On average, each EU habitant in 2010 produced an amount of 154 kg of packaging waste whereas in 2019 the value rose to 178.8 kg (Eurostat, 2022b). The major stake of waste produced was cardboard which accounted for 40,6% of the waste volume produced. Plastic and glass came next with their volume being very similar, they accounted for 19.4% and 19,1% respectively (Eurostat, 2022b).

Focusing on glass packaging waste generation in Portugal, the weight produced increased in the last few years. It can be depicted in Figure 1.

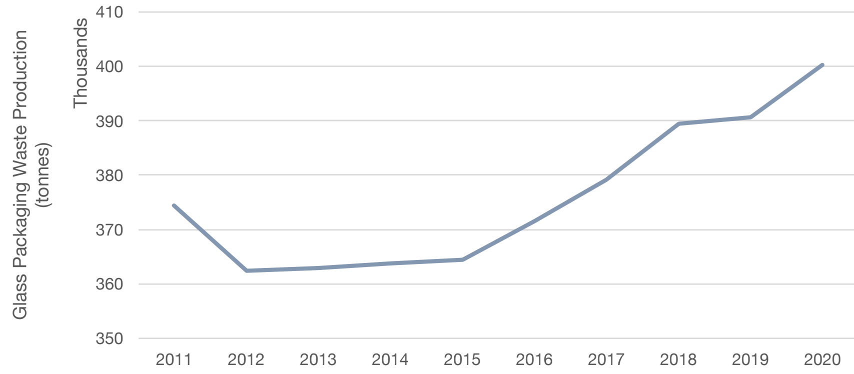

Figure 1 - Glass Packaging Waste Production in Portugal (tonnes) (Eurostat, 2022a)

One critical target enforcement is the EU's targets for waste management that, as it is going to be developed next, Portugal still did not meet. Table 1 depicts the targets (for recycling or reuse) imposed for glass and packaging waste in general.

Table 1 - Recycling Targets for Glass and General Packaging (REA | APA, 2021)

	2011	**2025**	**2030**
Glass Packaging Waste	60%	70%	75%
All Packaging Waste	55%	65%	70%

As it is possible to conclude, several waste management targets imposed by the EU have not yet been met. The recycling percentage of the EU for glass waste is 76% whereas Portugal is placed below the average with only 52.5% of the glass being recycled (Eurostat, 2022a). This value is even lower than the 2011 defined target.

Looking at the top-performing countries (among the data available), four countries have a recycling rate of over 90% of their glass waste generated (Eurostat, 2022a). Another interesting comparison can be between Portugal's and Belgium's situation on glass generation and recycling. Belgium generates approximately the same amount of glass packaging waste as Portugal although the recycling rates are very different which suggests that Portugal has a lot to improve.

In addition, it is important to mention that there are two types of glass beverage packaging nowadays. The first is the one-way bottles which means that these types of bottles are only used once by the consumer along the value chain. The second is the reusable glass bottles, which means that the bottles can be refilled again and reused by the consumer several times. These latter ones are less common that the one-way packaging.

To conclude, there are several European countries that are far from achieving the targets set by the EU. In order to better understand how Portugal can increase the glass recycling rates market, it is important to focus specifically on the Portuguese waste flows of glass and its market. The next subsection will reflect on those topics.

2.1.2 Portuguese Packaging Waste Management System And Market Figures

In Portugal, household packaging waste collection is of the responsibility of *Sistema Integrado de Gestão de Residuos de Embalagens* (SIGRE), the Portuguese integrated system for packaging waste management. It needs to be highlighted that all one-way packaging containers have to be covered by the SIGRE in order to be commercialized (*Sociedade Ponto Verde*, n.d.). Reusable glass containers are part of other waste management systems (APA, 2021a).

According to Sociedade Ponto Verde (n.d.), the collection system is made through selective disposal in dedicated communitarian containers for certain materials, one of which is glass. Next, the valorisation practices are carried out by *Sociedade Ponto Verde* which then sells the materials again to producers and packagers as described in Figure 2:

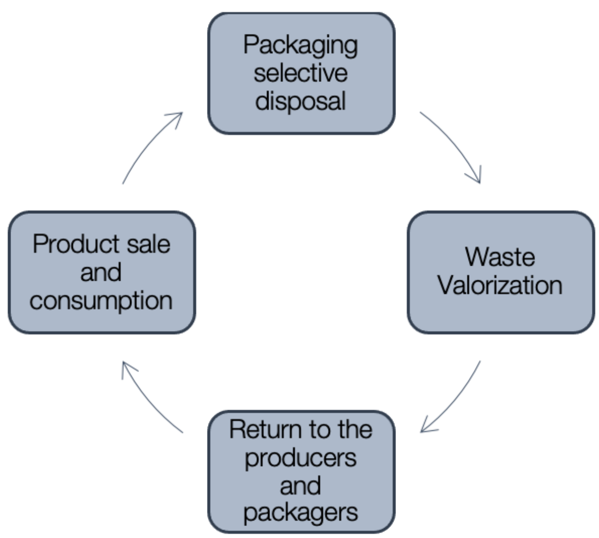

Figure 2 - Current Waste Valorization Scheme

Regarding the performance of the glass valorisation system, it was 56% in the year 2020 which is still significantly distant from the targets defined by the EU for recycling or reuse for 2025 (REA | APA, 2021). Hence, there is a need for new solutions that incentivise the effective collection of glass packaging in order to increase recycling rates.

The Portuguese glass packaging market positioning is important to be detailed and analysed. The main focus will be on the glass beverage packaging and not on the glass packaging in general which would include, for example, perfume containers. Table 2 shows the glass packaging declared in Portugal (for <2L non-reusable, one-way containers). The data is expressed in subcategories of products where some of which are of interest to this work, as it is going to be explained after.

Table 2 - Glass Beverage Packaging Market Placement (3Drivers & NOWA, 2020)

Category	Units (millions)	Total weight (kt)
Water	96.5	16.4
Juices and Sodas	129	31.2
Beer	421.2	187
Wine	164.5	77.1
Spirits	78.7	62.3
Total	889.8	374.5

The subcategories that are going to be studied are the ones that can be easily implemented in a DRS. These subcategories are, inside the glass packaging industry, water, juices and sodas and, beers which are the easiest to implement and that are more consensual in other countries' systems (3Drivers & NOWA, 2020). They account for 72.6% of the units of bottles produced per year and 62.6% of the total weight.

Furthermore, glass bottles contribute 35% of the total units placed in the bottle packaging market compared to other materials such as plastic (49%), aluminium cans (12%) or steel (4%) (3Drivers & NOWA, 2020). However, when accounting for the total weight, it represents 91% of the total weight of the bottle packaging industry which is significant.

To sum up, the Portuguese market for glass beverage packaging waste is considerably large. Therefore, the need for solutions to recycle more is needed as with other countries that already implemented some systems. Some of them found their solution in the DSR. Next, the main regulations, laws and incentives are going to be presented.

2.2 Waste Management Regulation, Legislation, and Incentives

In this subsection, the laws and incentives related to waste management and the DRS are going to be described. Firstly at a European level and, secondly, in the Portuguese legislation that follows also several guidelines from the EU's policy on this topic.

2.2.1 EU Intervention In Packaging Waste Recycling Targets And Incentives

EU's influence over the member states is powerful and aims at sharing a common vision for Europe. Some changes, such as climate change action, have to be a common goal since every contribution is important to mitigate the global consequences. Therefore, due to this influence, the EU has decided, over the years, to impose laws and targets in order to promote some good practices. Over the years, these environmental laws became stricter and more demanding. Next, an overview of the EU policies related to packaging waste is going to be described.

Since 1994 Packaging Directive was in place with several updates and reviews over the years. This directive was updated in 2018 to help meet the EU green deal targets and the Circular Economy Action Plan (CEAP) (discussed next), where it is ensured that until 2030 “all packaging on the EU market is reusable or recyclable in an economically viable way” (European Commission, n.d.-d). In addition, 2018’s review enforced the Extended Producer Responsibility (EPR) schemes concept and set the glass packaging recycling target of 70% by 2025 and 75% by 2030 (European Commission, n.d.-d).

The EPR schemes are a step further into the environmental policy incentives needed for the environmental transformation of the production processes that pollute. The EPR is based on the “polluter-pays” principle transversally enforced in all waste management (European Commission, 2020). Therefore, the responsibility of the waste treatment is transferred to the producer and not to the consumer.

Until 2020, the targets in force were part of the 7th Environmental Action Programme (European Commission, n.d.-b). The targets and recommendations that were presented in this document were related to waste management in general and offered a lot of solutions and frameworks to the member states to adopt more good practices. Unfortunately, some of the countries did not meet those targets yet. Despite that, the member states could generally increase their recycling and recovery rates and improve their waste management systems. In other words, every country has now more awareness of the waste issue than before the document was published.

In 2020, the EU signed a new document that is currently in force which is the new CEAP, part of the European Green Deal (European Commission, n.d.-a). This plan is aiming at relieving the pressure on the exploitation of natural resources trying to assure that the resources are kept in the EU’s life cycle for as long as possible including glass (European Commission, n.d.-a). Currently, the CEAP is incentivizing the review of the packaging waste initiative which aims at incentivizing recycling and also increasing the amount of recycled material in packaging (European Commission, n.d.-e).

Furthermore, the EU’s long-term environmental strategy leads to the objective of achieving EU carbon neutrality by 2050 (European Commission, n.d.-c). Achieving net-zero greenhouse gas emissions and being compliant with the Paris Agreement (European Commission, n.d.-c). One of the areas in which this deal will be aiming is the packaging.

In conclusion, the EU has a critical role when it comes to enforcing the measures that will lead to a more sustainable future. However, not only the EU has an important role in it, but also the governments in the member states. In this work, as the Portuguese implementation will be studied, it is important to focus further on the local measures and incentives to meet the EU waste targets.

2.2.2 Portuguese Legislation And DRS Incentives

New laws are arising in Portugal in order to meet the targets imposed by the EU legislation, besides the fact that there is a delay in imposing them, the laws should have to be followed by Portuguese companies and consumers in 2022.

As a matter of fact, the rules for the implementation of this system are planned for plastic and glass containers. However, the glass may suffer a law review by the year 2027 in order to assess the effectiveness of this system for this material (3Drivers & NOWA, 2020).

In Portugal, there are three major strategic plans related to waste management where packaging waste is included. The *Plano Nacional de Gestão de Resíduos* (2014-2020), *Plano Estratégico para os Resíduos Urbanos* and the *Plano de Ação para a Economia Circular* 2017-2020 (3Drivers & NOWA, 2020).

The major one is the *Plano Nacional de Gestão de Resíduos*, Waste Management National Plan, which has several targets along with different sectors of the economy. A new plan is about to be approved lasting until 2030. The glass packaging is included. Some of the measures included are related to glass packaging and are in line with the EU directives and, more precisely, with the CEAP (APA, 2021b). Namely, the assurance of a more effective waste collection and its treatment, promoting the self-sufficiency and competitiveness of the residue sector (APA, 2021b).

Looking back to some laws from the past that are important to understand the current situation and the motive to decide to implement a DRS in the near future.

In 2011, the Portuguese government introduced a law that stated the EPR scheme, in line with the EU's directive (3Drivers & NOWA, 2020). Then, in 2017, another law is put in place where the waste flows need to be stated precisely. In addition, several specifications, such as material type, number of units and the waste management system chosen for the collection of packaging put on the market have to be declared to the *Agência Portuguesa do Ambiente* (APA), the Portuguese Agency of the environment (3Drivers & NOWA, 2020).

In 2018, one pivotal law related to this work was published. Among other things, it aims at creating incentives for the collection of one-way beverage containers and, thus, creating a more efficient recycling route in order to meet the targets settled by the EU. The incentives mentioned are the creation of a DRS for plastic, glass and metal (iron and aluminium) beverage containers (3Drivers & NOWA, 2020). Until 2019, the law foresees a small-scale test of the implementation of the DRS scheme for plastic. From the beginning of the year 2022 onwards, the law imposes the existence of a deposit system on every one-way container made of the materials mentioned above.

Once the bottle is returned, the deposit would not be returned in cash but in one of two ways according to the law. The first can be given that value in coupons that allow the consumer to spend the money on the store where they left the bottle. The second way is for the money to be given to a social non-profit organization.

Following the focus on the EU and Portuguese legislation regarding waste targets and incentives, it is relevant to analyse the DRS in other countries to understand their differences and similarities which will be discussed next.

2.3 DRS in Other Countries

The efficiency of the DRS depends on the settings and design made (*Deposit-Refund System (DRS)*, 2019). In this section, the standard DRS scheme is shown. In addition, since the maximum efficiency possible is aimed to be achieved in the Portuguese future large scale system, it is necessary to look into the shape of the systems already in place. After the standard model explanation, a comparison between several countries that adopted this system for glass bottles will be analysed taking into consideration aspects and characteristics. Information concerning the governance, the funding and deposit fees and, finally, the number of collection points will be compared.

2.3.1 Standard DSR Schemes

In order to mitigate the impact of disposal of packaging waste that, as mentioned before, has an impact on the environment and needs to be reduced, measures need to be taken. The rise of collection systems is a viable option that is adopted in several European countries as well as in other places around the world.

According to Schulz (2011), there are two important factors when describing an optimal collection system. The first factor is a system that is convenient to the user hence having many places nearby for the consumer to return bottles. The second one is a system that rewards the consumer for the pain of having to return the bottles again to the store instead of disposing them in the garbage which can be seen as much more convenient.

The DRS that will be studied throughout this work has these two characteristics. Aiming at increasing the recycling rates of beverage packaging (whether plastic, aluminium or, in this case, glass), more countries are searching for this solution since the EU's targets have to be met.

There are two important flows when describing a DRS – the material and the money flows (in Figure 3). The material flow is constituted of the following actions (represented by the blue arrows):

- Prod.1 and 2 flow: The glass bottles are filled and move to the Retailer, or Hotels, Restaurants and Cafés (HORECA) facility that will sell the beverage to the consumer.

- Prod. 3 flow: The consumer, instead of disposing the bottles, will return them to a collection point via a manual collection by a store operator or via a Reverse Vending Machine (RVM) that does this return process automatically.
- Prod. 4 and 5 flow: Once the used empty bottles are in the store, their ownership is passed to the system administrator that will arrange the collection, transportation, counting clearance and sale to the recycling plant. In flow 4, there are variants such as the state of the bottles which can be shredded or not.
- Prod. 5 flow: The recycled material can be sold again to bottle producers.

Concerning the money flow (see Figure 3), the main convention is that, when the bottle changes ownership, the deposit fee is transferred in the opposite direction. The payments and money transfers are the following:

- Dep. 1 and 1.1 transfer: The Retailer pays the deposit to the beverage producer when purchasing merchandise. Then, the producer transfers that fee to the system's administrator.
- Dep. 2 and 3 transfer: The consumer pays the deposit when buying the beverages. The deposit recovery happens when returning the bottles (usually not in money but as a discount ticket in the store).
- Dep. 3.1. transfer: Given the number of bottles returned in a certain store, the system's administrator covers the deposits that collection points transferred to customers.
- RHF transfer: In addition to the deposit transfer 3.1, a compensation fee is paid to the establishment to cover the costs of collection. This fee is called the Retail Handling Fee (RHF).
- Op. 1.1. transfer: This transfer is a fee that is paid by the producer to the system's administrator for every unit placed in the market. This fee only exists in some systems.
- Market Income transfer: This money flow is created for the sale of material to Recyclers.

It is important to highlight that the system described in this section is the basic one and there might be some differences in the scheme depending on the country/region that is implemented. In Figure 3, the standard scheme can be depicted.

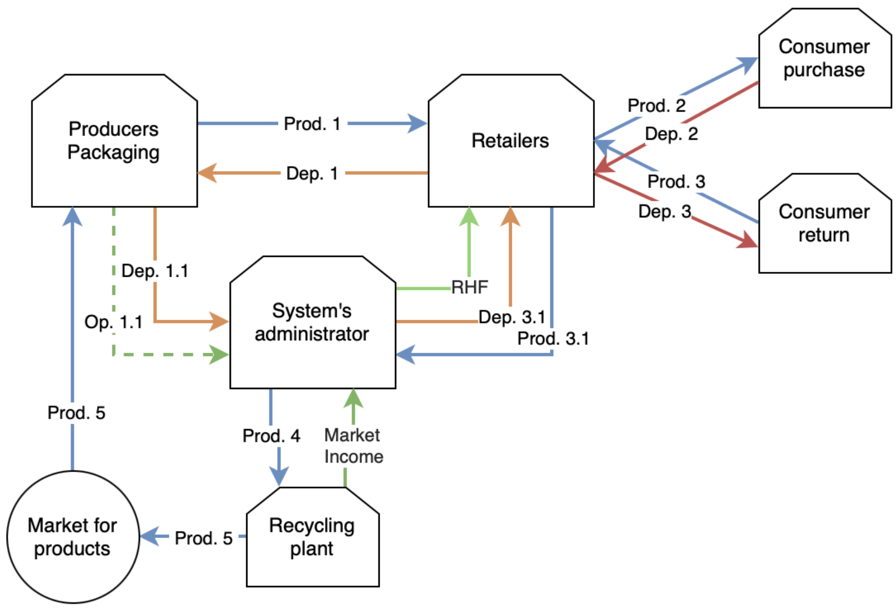

Figure 3 - DRS Standard Materials and Money Flows (3Drivers & NOWA, 2020; Dace et al., 2013b)

To sum up, 3Drivers & NOWA (2020) found four main purposes of the DSR schemes. The first one, as mentioned before, is to increase the collection rate of one-way containers. The second goal is to obtain higher quality materials to be recycled, only possible with this level of differentiated waste collection. The third is more a consequence which is the fact that littering will be reduced because there is a monetary incentive to return bottles. The fourth is to provide a contribution to true circular economy schemes which are the future

2.3.2 Countries With Glass Bottles DRS

Among several European countries that have DRS, they have common similarities but also differences. It is important to study these systems since Portugal's implementation can be based on what they have best to offer. In this section, a benchmarking study will be made taking into account several criteria regarding the countries that have adopted the glass DRS.

The EU countries where was possible to collect data regarding glass DRS from were Iceland, Finland, Denmark, Germany, Estonia, Croatia and Lithuania. These are the 7 countries that, despite the specifications that the glass collection has, have adopted the glass DRS among 10 EU countries that have some sort of DRS for some kind of packaging.

Portugal is the only European country that has decided to introduce the DRS in the near future whereas Spain, France, the United Kingdom, Austria, Slovakia, Latvia and Romania are only considering this a possibility (*Deposit-Refund System (DRS)*, 2019).

It is also important to mention that most of the countries studied here use a reusable system for the glass bottles for the HORECA channel without even the regular consumer realise it (3Drivers & NOWA, 2020).

Due to the rising number of European countries thinking of implementing this kind of system, it is feasible to assume that this system may be the path to the beverage packaging recycling rates increase. Next, the already working system's governance will be analysed.

2.3.3 System's Governance

Concerning governance, the countries adopted some management strategies for these systems that have some similarities as well as some different approaches.

According to 3Drivers & NOWA (2020), there are several tasks that are the systems administrator's responsibility. As expected, in the system's administrative, operational, financial and information management. Also, the deposit management derived from a flux of millions of bottles annually and all the operational management of the RVM and other return points issues, the material collection (except in the German system), the bottle counting and filtering, and finally the sale of the collected material.

Table 3 - DRS Administration and Ownership (by Country) (3Drivers & NOWA, 2020)

Country	Type of Entity	Ownership
Iceland	Private Non-profit	Managed by related industry and the State. The scouts are also shareholders.
Finland	Private Non-profit	Half owned by producers and half by retailers
Denmark	Private Non-profit	Almost 100% owned by producers, mainly breweries.
Germany	Private Non-profit	50% owned by a Retail Federation and 50% by Food and Drink Industries Federation
Estonia	Private Non-profit	Owned by the producers
Croatia	Public Non-profit	Public
Lithuania	Private Non-profit	Owned by the producers and retailers. The only case of competitive licencing.

From Table 3, there are some common similarities among the systems. The major one is that all the systems are private (except for Croatia) and don't have the objective of profiting from this activity. However, the systems also have some governance differences such as the ownership of the management entity. Some of these countries share the ownership between the Retailers and the producers and, others, are owned only by the producers or even the state.

According to 3Drivers & NOWA (2020), the only case where there is a model of competitive licencing for the management system is in Lithuania although, currently, this model is only theoretical since there is only one association interested.

Next, the systems' funding and deposit fees will be presented.

2.3.4 Funding And Deposit Fees

As expected, these systems have costs that need to be covered by some entities. In addition, it is important to mention that, at least currently, these systems are not self-sufficient and need investment, usually public. However, the countries that adopted these systems have dealt with the operational costs in different ways.

First of all, according to (3Drivers & NOWA, 2020) there are three main sources of income for DRS that are usually used to cover part of the operational costs:

- Fees imposed on producers for every packaging unit placed in the market
- The sale of the packaging materials
- Unclaimed deposits

Moreover, there are other fees related to the registration into the system for the producers. However, according to (3Drivers & NOWA, 2020), this fee is a unique payment with the purpose of paying for the direct registration administrative process.

Although there are some differences in the way the system is funded, the operational fees are present in every case study in this work. They are related to the EPR imposed by the EU.

In Table 4, the deposit and handling fees are shown.

Table 4 - DRS Deposit and Handling Fees Values (by Country) (3Drivers & NOWA, 2020)

Country	Deposit value	Handling fee (manual)	Handling fee (automated)
Iceland	0.13	0.02	
Finland	0.10 to 0.40	0.0193	0.019 to 0.03
Denmark	0.13 to 0.40	0.01 to 0.02	0.002 to 0.0095
Germany	0.25	Not paid. The material is property of the retailer	
Estonia	0.1	0.0115 to 0.013	0.0215 to 0.033
Croatia	0.06	0.013	0.016
Lithuania	0.1	0.0138 to 0.02	0.0144 to 0.0328

Other sources of revenue are fees that can be applied such as a fee when there isn't a planned collection by the Retailer by its own fault. Or money earned through the leasing, rental or sale of the operational equipment such as for the collection.

2.3.5 Collection Points

As mentioned before, these systems create incentives for the consumer to return the bottles again. To do so, the consumer needs to have collection points where it feels convenient to deliver back the bottles. Table 5 shows the values for the return packaging of each country and also the number of collection points in the two possible ways. The first is through the use of an RVM that counts the bottles and gives back the correct compensation automatically as well as refuses/rejects bottles or items that do not belong to the system. The second way is through a store's employee responsible for counting and sorting the bottles and refunding the consumer.

Table 5 - DRS Returned Packaging and Number of Collection Points (by Country)(3Drivers & NOWA, 2020)

<table>
<tr><th>Country</th><th>Returned packaging (millions)</th><th>Number of RVM</th><th>Manual collection</th></tr>
<tr><td>Iceland</td><td>Unknown</td><td>10</td><td>50</td></tr>
<tr><td>Finland</td><td>1 700</td><td>4 000</td><td>14 000</td></tr>
<tr><td>Denmark</td><td>1 200</td><td>3 170</td><td>15 500</td></tr>
<tr><td>Germany</td><td>Unknown</td><td colspan="2">135 000</td></tr>
<tr><td>Estonia</td><td>231</td><td>717</td><td>903</td></tr>
<tr><td>Croatia</td><td colspan="3">Unknown</td></tr>
<tr><td>Lithuania</td><td>582</td><td>1 006</td><td>1 713</td></tr>
</table>

As mentioned before, these countries have reusable systems for the glass bottles in the HORECA channel instead of recycling ones which means that these values represent the Retail operations serving the end-consumer (3Drivers & NOWA, 2020).

2.4 Barriers to the Implementation of Glass DRS

The DRS systems can, as mentioned before, cover not only glass bottles but also other materials such as plastic, aluminium or metal. When looking at the range of the different candidate materials for DRS schemes, plastic is by far the broader one. Therefore, the question must be asked. What are the barriers and limitations that glass has when implementing a DRS?

According to 3Drivers & NOWA (2020) the main ones are:

- The weight of glass bottles compared to other packaging materials (for the same volumetry). This is a limitation to transportation and handling;
- Glass cannot be compressed without being broken or shredded. This is not only a danger to the consumer and the operator. Also, by being broken in the RVM (a possibility), it makes noise which is undesirable for Retail stores. If not broken into pieces, the glass bottles can occupy a considerable amount of space in the store (what happens in the reusable model);
- The glass collection, when together with plastic, can duplicate the space needed for the collection in the stores.
- There is also a dispute between the DRS and the reusable models. Some countries have decided to adopt the reusable model instead of the DRS. This is due to the fact that glass is the most easily reusable material among the common packaging;
- The convectional separate collection of glass is the cheapest among the other materials.

Moreover, there are some exemptions in the glass DRS regarding the type of beverage. Wine and spiritual drinks are excluded (3Drivers & NOWA, 2020). The DRS in place are in northern Europe where the wine industry is not big, therefore, wine bottles come from imports thus excluded from the scheme. Also, the wine is excluded due to undesirable odours that this liquid might cause. Regarding spirits, these drinks do not have normalized shape bottles and several might be even made of opaque glass which difficult for the whole process of collection and recycling.

There is also a note to be made concerning the unclaimed deposits. When a system that supposedly has the mission of creating the right incentives for the return of the bottles, depends on the unclaimed deposits to fund itself, there are to opposing incentives. On the one hand, the return is desired by the system to fulfil its mission. On the other hand, by funding itself through unclaimed deposits, the system loses the incentive to fulfil its mission since it desires the consumer to not return the bottles back.

Besides these limitations, EU countries are aware that the glass waste recycling targets are not yet met, therefore, several countries are considering adopting these systems because they can bring an increase in the glass recycling rate.

2.5 The Challenge

In this section, the main challenge of this work was presented and then detailed.

Taking into account all the packaging waste current issues mentioned in this Chapter and also the targets for recycling imposed by the EU, countries such as Portugal ought to rethink their waste collection strategy with the purpose of increasing their waste recycling rate. The implementation of the Portuguese DRS is forecasted to happen in the close future. Therefore, the strategic reverse logistics network must be studied and planned in order to achieve a better design for an optimized solution.

The main challenges addressed in this work are the following:

- A literature review on the topic of DRS and, reverse logistics strategic network design models;
- The characterization and planning of the logistics network for the implementation of the glass DRS;
- The modelling of a network design model that translates the DRS scheme requirements;
- The model validation through the use of real empirical data.
- The analysis of the outcomes and conclusion remarks.

Chapter 3 – Literature Review

In this Chapter, concepts and research topics such as waste management, DRS schemes, and network design for reverse logistics are explored in the existing academic literature.

Section 3.1. will analyse first some Reverse Logistics concepts applied to waste management in a very introductory and broader manner. Then, in section 3.2. will be performed a systematic literature review of the DRS concept. Finally, the conclusions concerning the research gap taken from it will be followed up in section 3.3. that will focus further on finding analogous reverse logistics network design models applied to waste management. In the end, section 3.4. will present the main conclusions from this Chapter.

3.1 Waste Management Reverse Logistics

Due to the rising amount of waste generated, solutions must be developed. Since, some years ago, the concept of circular economy of the supply chains became part of the world's daily life. This is where reverse logistics comes in place, especially applied to waste management. Suzanne et al. (2020) mention in their literature review four types of reverse logistics topics which one of the types is connected to waste management. In addition, the authors traced back several terms used in the reverse logistics area. "Sustainable Development" appears in the literature around 1977, "Reverse Logistics" is mentioned next nearby 1984 in general terms but only around 1998 is referenced as a term in the area of circular economy, then, after 2000 other terms appear such as "closed-loop Supply Chain" or "Green Logistics".

Moreover, in order to introduce the reverse logistics subject, it is relevant to have a general definition of it. Agrawal et al. (2015) stated that the most common and first widely accepted definition of reverse logistics is the definition provided by (*Going Backwards: Reverse Logistics Trends and Practices*, n.d.) which states that:

"RL is the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal."

Currently, the need for reverse logistics solutions is still arising. A piece of evidence pointed out by Mollenkopf & Closs (2005) is that there were some pressures that lead to the reverse logistics channels development. The fact that waste management laws and industry regulations are becoming increasingly stringent and the increase of the landfilling cost also contribute to this development. An additional incentive is related to the EPR concept that led to the quest for not only cost-efficient but also cost-reduction solutions where reverse logistics development fulfilled this gap. Although stated in 2005, these statements remain relevant in the present (*A European Green Deal | European Commission*, n.d.). Additionally, de Brito & Dekker (2002) highlighted the fact that Reverse Logistics has the purpose of taking advantage of the value that the end products might still have.

For instance, in terms of glass beverage packaging, the value present in the end-use product (the empty glass bottle) is the fact that the material is still recyclable and can give birth to new bottles even though raising some controversy as mentioned in Chapter 2.

Concerning standard Reverse Logistics processing, there are four main steps that are worth mentioning: Receiving, Processing, Sortation, and Disposition/Disposal (Stock & Mulki, 2009). In the case of beverage waste, the reverse logistic processing starts with the collection, then passes through sorting and processing and finally the reprocessing/recycling giving the collected material origin to new products.

Focusing on a stakeholder theory perspective, the reverse logistics entities involved in the process can be also characterized. Govindan & Bouzon (2018) identified the main contributors and entities present and needed in this kind of system. By crossing references from other sources over the years, the researchers could manage to find that, the stakeholders involved in these networks are the government and legislation agencies, the customers, the society and media, the competitors and suppliers, the organization itself, and its employees.

To conclude, reverse logistics can be a very broader topic even when applied to waste management. There are several basilar concepts that need to be taken into account in the first approach to this topic. The next section will narrow the literature review to the main topic of this work which is the DRS, part of the reverse logistics process.

3.2 DRS Literature

In this section, a systematic literature review will be made of the DRS topic. In subsection 3.2.1. the article selection criteria are presented. Then in section 3.2.2. the article classification methods will be explained. Then, in subsection 3.2.3., the articles on the topic will be classified accordingly and analysed further. Finally, in subsection 3.2.4., the research gaps identified will be clearly defined and the main conclusion of this Chapter will be developed.

3.2.1 Article Selection

In this section, the article scouting and selection criteria will be explained and conclusions concerning the number of articles will be pointed out.

A systematic literature review on the keywords “Deposit Refund System” is made with the purpose of searching all the existing literature/papers on this topic. The *Scopus* platform was used as the base database of articles. Two filters were placed. The first was related to the language, which had to be in English, and the second, constraining the research only to scientific articles.

In the first approach, *Scopus* returned a total of 91 articles written in English – the ones that were selected to proceed with the data treatment. Then, by carefully reading all the abstracts, another 10 were removed because they were off the topic of the DRS applied to waste management (some were related to, for example, the deposit fees left in hotel facilities).

A total of 81 articles were the main output and the ones focusing on DRS schemes applied to waste management, ranging from 1984 to the present, 2022. Therefore, it is feasible to assume that the literature on this topic is scarce. In addition, as it is going to be developed next, there are critical research gaps when it comes to analysing deeper these schemes although several are already established for several years to the present.

In Figure 4, it is possible to understand the distribution of articles on the DRS topic over the years. The separation was made over five-year periods. Even though it is still low, interest in this topic can be perceived due to the positive trend in the number of articles published over the years.

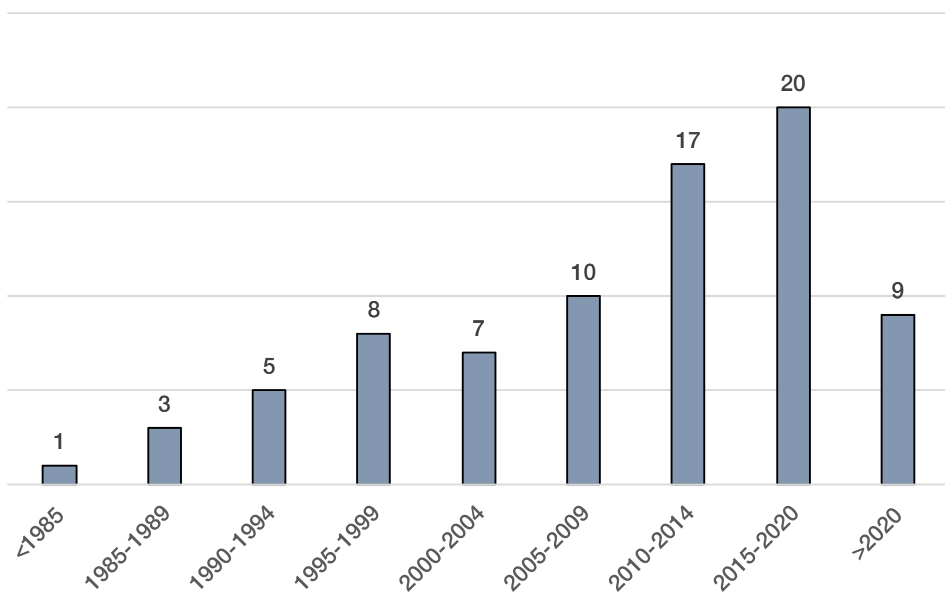

Figure 4 - Number of Articles Published per Half-Decade (1984 to 2022)

3.2.2 Articles Classification Method

The main purpose of this subsection is to try to understand the topics that the DRS research focused on over the years with the main purpose of finding a research gap and also exploring deeply the world of the DSR schemes.

Without the purpose of making the literature review comprehensive, the articles were classified down to the year where the first DRS system in Europe is referred to in the research which was 2013 for a Latvian system (Dace et al., 2013b). It is interesting to also acknowledge that the first DRS system introduced in Europe was by Sweden in 1984 (Renewable Matter, 2021). However, no relevant research until 2013 written in English mentions any DRS applied to beverage packaging.

In this work, four types of article analysis are made:

- Analysis 1: By type of material studied
- Analysis 2: By its research objectives
- Analysis 3: By the nature of the study
- Analysis 4: Its connection to Network Design

Analysis 1: Material type studied

Considering this category, the articles will be classified according to the type of material or product analysed in the study ranging from Beverage Packaging to Waste from Electrical and Electronic Equipment (WEEE). The articles can then be grouped by the same type of material.

Analysis 2: Research objectives

The articles were found conceivable to be classified also by the article's main research goal. In this way, one of the objectives could be to assess the conditions before the implementation phase or justify the DRS implementation. The second goal found was of analysis of already implemented systems and the research had the purpose of improving those systems' viability. The third goal found was to compare mainly two things. Either the goal of comparing different DRS systems or comparing the DRS system with other collection options.

To sum up, there are three identified research objectives which can be the justification for the DRS implementation, the analysis of an already existing system and, lastly, the comparison objective.

Analysis 3: Nature of the study

The third classification used to classify the articles into categories was their nature. After splitting between qualitative articles and quantitative ones (which is a good starting approach to classification), there were perceived to exist five main categories of articles present in DRS literature.

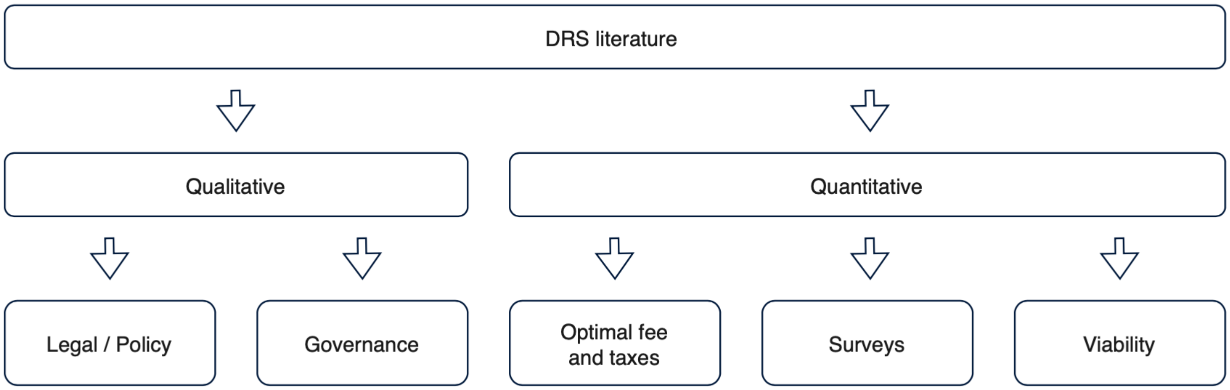

Figure 5 - Analysis 3 Nature of the Study Classification

As depicted in the Figure 5, there were two categories perceived on the qualitative side. On the one hand, the "Legal/Policy" category referred to the legal part of the DRS or the relation to waste management policies. The "Governance" category is related to the governance structure of the DRS and the way it works schematically. On the other hand, on the quantitative side, three categories were recognized. The "optimal fee and taxes" category is related to the DRS optimal return fee, other fees, or taxes imposed on the waste management process. Then, the "Surveys" category gathers surveys, for example, to assess the perception of consumers over the DRS. Then the "Viability" category aggregates viability analysis, which includes all types of analytical analysis such as economical (cost), environmental and efficiency of DRS systems.

Analysis 4: Connection to Network Design

This last way of analysing the literature is the most simpler of the four. It will assess if there is any DRS literature related to strategic network design modelling. This analysis is decisive due to the nature of this work which aims at designing a strategic network model for the implementation of a glass DRS in Portugal. This analysis was extended to all the DRS articles found.

3.2.3 Article Analysis

Table 6 depicts the articles found and their classification according to the principles described in the previous subsection.

Table 6 - DRS Articles Classification (2013 to 2022)

	Analysis 1	Analysis 2			Analysis 3							Analysis 4
Work	Material	Justification for implementati	Analysis to already established	Comparison	Legal/policy	Governance	Optimal Fee / Taxes	Surveys	Effectiveness /Efficiency	Economic	Environment al	Network Design
(Milovantseva & Saphores, 2013)	WEEE	*						*	*			*No*
(Acuff & Kaffine, 2013)	Generic	*									*	*No*
(Dace et al., 2013b)	Beverage	*		*					*	*		*No*
(Uwasu et al., 2013)	WEEE			*			*			*		*No*
(McEvoy, 2013)	Generic	*			*							*No*
(Yokoo & Kinnaman, 2013)	WEEE	*			*		*					*No*
(Buffington & Peterson, 2013)	Beverage	*							*			*No*
(Dace et al., 2013a)	Beverage	*								*	*	*No*
(Saphores & Nixon, 2014)	Beverage	*			*			*				*No*
(Kaffine, 2014)	Other						*			*		*No*
(Hovi et al., 2014)	Generic			*	*							*No*
(Gupt, 2015)	WEEE	*			*							*No*
(Sun et al., 2015)	WEEE	*					*	*				*No*
(Chen et al., 2015)	Other			*	*				*	*		*No*
(Özdemir-Akyildirim, 2015)	Several			*					*	*		*No*
(Hamilton et al., 2014)	Other		*	*	*		*				*	*No*
(Simon et al., 2016)	Beverage			*							*	*No*
(Rahman & Mayer, 2016)	Other	*			*							*No*
(Kling et al., 2016)	Generic			*	*					*		*No*
(Bhaskar & Turaga, 2018)	WEEE		*		*			*				*No*
(Linderhof et al., 2019)	WEEE	*					*		*			*No*
(Tiwari et al., 2019)	WEEE			*		*						*No*
(Warrings & Fellner, 2019)	Beverage			*					*			*No*
(Cudečka-Puriņa et al., 2019)	Beverage	*		*					*			*No*
(Honma, 2019)	WEEE	*		*			*					*No*
(Kursah & Baabereyir, 2019)	Other	*					*	*				*No*
(Zhou et al., 2020)	Beverage			*		*						*No*
(Li et al., 2020)	WEEE		*				*		*			*No*
(Bala et al., 2020)	Beverage	*		*							*	*No*
(Abejón et al., 2020)	Beverage			*							*	*No*
(Roca i Puigvert et al., 2020)	Beverage	*						*				*No*
(Y. Wang et al., 2020)	Beverage		*	*		*			*			*No*
(Gong et al., 2021)	WEEE	*		*		*			*	*		*No*
(Calabrese et al., 2021)	Beverage	*	*	*		*			*			*No*
(Šuškevičė & Kruopienė, 2021)	Other			*					*			*No*
(Boros et al., 2021)	Beverage	*						*				*No*
(Schneider et al., 2021)	Beverage	*					*			*		*No*
(J. Wang et al., 2021)	WEEE			*		*	*		*	*		*No*
(Berck et al., 2021)	Generic		*						*			*No*
(Colelli et al., 2022)	Beverage			*					*	*		*No*
(Roca et al., 2022)	Beverage	*						*				*No*

Analysis 1: Material type studied

First of all, the articles were classified by taking into account four relevant categories of materials that are "Beverage Packaging", "WEEE", "Generic" and "Others". The first one, and the one that has more articles includes all types of one-way beverage packing containers waste such as glass, plastic, and aluminium (Schneider et al., 2021; Warrings & Fellner, 2019). Then, "WEEE", the second most mentioned category, refers to all electric entities such as household appliances, electrical waste, or batteries (Bhaskar & Turaga, 2018; Tiwari et al., 2019). The "generic" category includes models that do not have any specific type of waste associated. For example, in models where the goal is to depict the waste panorama in a broader manner (Kling et al., 2016), or ways to cooperate with climate action (Hovi et al., 2014). Finally, the "Others" category includes articles that have a specific material to be studied only mentioned in one article, such as lubricating oil (Hamilton et al., 2014), or scraps (Kaffine, 2014), among others. Figure 6 shows the four categories analysed compared. As it is possible to confirm, there is a strong prevalence of literature concerning Beverage Packaging Waste and WEEE which indicated that these materials are the most commonly studied.

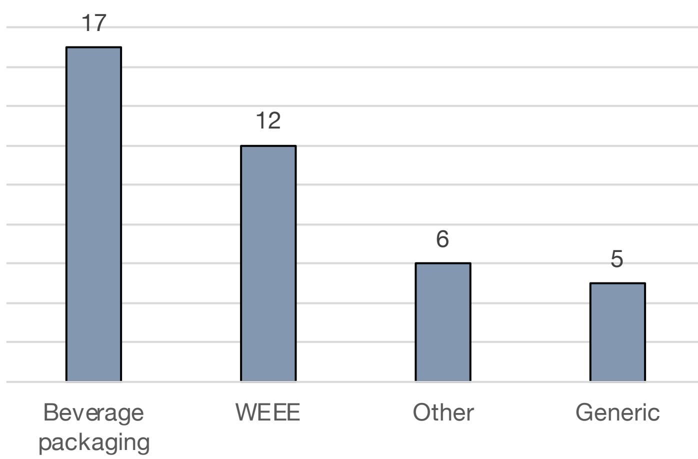

Figure 6 - Number of Articles by Material Type (2013 to 2022)

Analysis 2: Research objectives

Moving to the article classification by topic, Table 6 describes the categories that were used to classify the articles. As referred before, either the works analysed had the purpose of justification the DRS implementation, the purpose of analysing an existing DRS, or comparing systems. In addition, the number of articles presented per category is shown.

Table 7 - Number of Articles by Research Objectives (2013 to 2022)

	Number of Articles
Justification for Implementation	22
Comparison	21
Analysis to Improve Already Established	6

Within the categorization by the article research purposes, by looking at Table 7, the first conclusion possible to take is that there are significantly more articles justification the implementation of a DRS than the ones improving the already established DRS. However, some research for improving already implemented systems such as the EV battery case study in China where they perform a study in which they conclude that, for a more effective collection, the collection subsidy should be increased (Sun et al., 2015).

Nevertheless, around 40 countries already implemented a DRS scheme, also, from a European perspective, over 130 million people have already access to a DRS for beverage packaging (Zhou et al., 2020). With issues concerning international climate cooperation and compliance, Hovi et al. (2014) point out that the DRS can be a way of mitigating those obstacles in an effective way. Moreover, as Simon et al. (2016) referred to, there are efficient ways to design waste collection systems. Therefore, the need to laying the ground for building efficient collection systems and its justification for the implementation of the DRS.

Several other articles categorized by analysis 2 were comparative. This type of analysis is important as a follow-up to many factors. For example, comparing different collection systems and beverage packaging materials in terms of environmental impact (Simon et al., 2016 ; Bala et al., 2020). Others rely on comparing different governance structures between DRS systems (Calabrese et al., 2021; Zhou et al., 2020).

Analysis 3: Nature of the study

Table 8 shows the classification by the nature of the research itself.

Table 8 - Number of Articles by Nature of the Study (2013 to 2022)

	Number of Articles
Effectiveness / Efficiency Viability	16
Economic Viability	11
Optimal Fee and Taxes	11
Legal / Policy	10
Surveys	8
Environmental Study	6
Governance	6

When categorizing by the type of analysis made in the article, the category that stands out is the study of the efficiency and effectiveness of the DRS. One key finding is that, in these types of waste management schemes, the efficiency of the recycling system is not correlated to how much the system costs. Recycling rates are higher when there is a monopolistic managing entity although, a competitive market also achieves acceptable recycling rates (Colelli et al., 2022). However, Dace et al. (2013b) refers that the system's cost is correlated with the quantity of packaging in the market.

Other categories also stand out, namely the economic analysis and fee determination articles. In order to assess the cost of the system from an economical perspective, Linderhof et al. (2019) perform a partial equilibrium model for small electric appliances. However, it summarizes the DRS into two economic instruments: a fee added to the price of the product, and a subsidy/fee paid to process the same product at its end-of-use. It also states that the DRS for bottles is very effective in terms of collection in the Netherlands. In terms of cost analysis, Dace et al. (2013b) perform an assessment of the main economic drivers and cost estimations for the implementation of a DRS in Latvia and conclude that the system's implementation will require a considerable amount of investment to be operational, the expenses for the Retailers are expected to increase since the flow of materials also increases and, on the producers' side, the waste management cost would also increase.

Finishing up the quantitative articles, the ones that have less research are connected to environmental assessments and surveys. Although less number of articles present on the environmental side, the ones that exist show high relevance because, as it was mentioned before, some of them compare the environmental impact of different waste management approaches and also compare it for different materials. Glass packaging is the most impactful among the materials although its recycling can be a way of avoiding environmental burdens hence being the most prominent to recycle while the DRS was neither the worst nor the best waste management system approached (Simon et al., 2016). Also, although not referring directly to beverage packaging, Acuff & Kaffine (2013) found that recycling subsidies or advanced disposal fees would bring more GHG emissions and also be more costly than the DRS when increasing the waste reduction ratio.

Sun et al. (2015) analyses a survey made to the Chinese consumer to assess the possibility of implementing a collection system for batteries. The survey showed that the inquiries were willing to pay a 13.6% increase in price to fund a dedicated DRS for battery collection and recycling. This article also helps to justify the fact that a DRS needs to be implemented and that can be a solution to the battery waste issue in China. Other articles analysing surveys assess the perception of consumers over DRS implementation. A survey made to Spanish consumers concludes that more information about the implementation of a new DRS could change the consumer recycling pattern (Roca i Puigvert et al., 2020).

From a qualitative perspective, the policy articles examined were always connected to other categories. For example, there is a relationship between recycling policies and the effectiveness of Municipal Solid Waste (MSW) systems (Saphores & Nixon, 2014).

Concerning governance structures, several articles introduce it, but only a few authors go deep into it. Calabrese et al. (2021) analyses several systems among the EU countries and identifies four different operating modes of the DRS and its governance structure. They conclude that the "operating-closing mode" is the most used one among the systems studied. The most prevalent system presented has a lower collection rate than other operational schemes. Furthermore, concerning governance, the authors identify four main entities in the DRS process – Operators, Producers, Retailers and Consumers. In the future challenges concerning DRS, the systems should, for example, be integrated with an intelligent collection (Zhou et al., 2020).

Analysis 4: Connection to Network Design

As mentioned before, this analysis is crucial for the development of this work since it will constitute the baseline for the DRS strategic network design planning to Portugal that is intended to be achieved. This topic will be developed deeply in the flowing section however, it is important to refer that no strategic or logistic modelling was seen in the literature. This analysis went further than the articles classified in Table 6 and searched the 91 articles belonging to the initial DRS article search. Even so, no article related was found. The main conclusion that urges from this fact will be explained next.

3.2.4 Network Design In DRS And The Research Gap

As it was mentioned before, without the proper tools for a good and solid network design for DSR, these systems might be a drag in terms of costs and inefficiencies. Also, the recycling rates can also be affected by an ill-designed network. Therefore, network design optimization is critical and needed in the literature for better system implementation. The network design problem, as it is going to be explained next, plans the strategic structure namely in terms of optimizing which facilities to open in a network and also which entities those facilities are going to serve optimally (Melo et al., 2009). With this optimization, recycling schemes can be efficient and costs can be reduced which is beneficial. This work intends at building a network design and planning model for the future Portuguese DRS. Therefore, the following conclusions are pivotal in this work.

When looking at all the 81 articles since 1984 that are mainly all the research that exists on this topic, the main takeaway is that there is no research on strategic network design modelling optimization for any of the systems in place. There is even a lack of research when it comes to theoretical models without the application of a case study. As mentioned before, the articles that are closer to it, are the ones concerning economic variables such as the deposit fee determination or economic viability models. However, no network optimization or planning is made.

Moreover, although almost all the articles found were based on case studies, there are not any related to Portugal or a region of Portugal which is already a gap in the research, especially for a country that aims at implementing this system in the close future. Although the DRS has the same principle for all, there are variants for every system depending on regional conditions such as the country's geography (Schneider et al., 2021). This fact confirms once more the need to study the implementation specifically for the case of Portugal and cover its nuances.

Only the report written by 3Drivers & NOWA (2020) develops this topic further and extensively describes the future system in Portugal in qualitative terms such as the legislation, figures of materials to recycle and flows of materials as well as the entities involved currently in the Portuguese MSW management. Notwithstanding, it misses the network design and even the future network planning (not in the scope of that report).

In conclusion, it is missing quantitative research that can serve to help to build better and more efficient systems and lead these systems to be effective and increase the recycling rates of countries that are struggling to meet required targets for packaging waste and other materials.

Since there is a lack of network design models, there is a need of exploring analogous models that can be applied to DRS with some differences. These similar models gather the same strategic decisions that this work's model will intend to also make. The most similar models found are strategic network design models applied to reverse logistics in waste management. Section 3.3. will focus on finding those models.

3.3 Network Planning Decisions

In this section, the goal is to provide support literature and network design models for this work. Subsection 3.3.1. will explore the research done on MSW management models in a very conceptual way. Then, subsection 3.3.2., will present and detail network design models applied to reverse logistics waste management.

As an introductory note, planning decisions can lay on three main types: operational, tactical and strategical. The strategic level, which is the level focused on this work, is the higher level among the three planning echelons. It is characterized by long-term planning of facilities, capacities, and locations. This work will also include some variables of tactical nature which is a level usually characterized by the allocation of goods and other medium-term planning decisions (van Engeland et al., 2020).

3.3.1 Strategic Planning Overview

In this subsection, an overview of the literature on MSW management models is going to be provided. Several categories and objectives are going to be taken into consideration.

Several resemblances between the DRS and reverse logistics systems for MSW can be found. This is especially relevant for this work since there are no DRS network design models yet developed.

As mentioned before, strategic planning can be seen as the long-term decisions influencing the supply chain. According to Bing et al. (2016), the network design of a global solution is part of the strategic planning of a MSW logistic system. The network design is needed to configure several processes such as collection, separation, sorting and reprocessing/recycling.

There are several ways of characterizing the existing research literature in the scope of this work which is the network design models for reverse logistics of waste management. The type of waste can be one of them, another can be the aim of the objective function. Or even, what will be discussed in more detail, the decision variables and parameters commonly used when building waste reverse logistics network design models. The most recent literature review of waste management network design models published in a relevant scientific journal was made by van Engeland et al. (2020) and it will be the constitution of the conclusions made in this subsection since it delivers clear conclusions concerning the nature of these models in a holistic perspective over the literature. Other reviews were assessed however, they were already much older than this one (Srivastava, 2007) or they presented a broader perspective on reverse logistics (not specific for waste management) (Agrawal et al., 2015b; Farahani et al., 2014).

Also, according to van Engeland et al. (2020), most of the waste management articles are case studies (in opposition to reverse logistics ones which are both case studies and not). Furthermore, these case studies are almost always applied to a specific waste type.

When speaking of types of waste, van Engeland et al. (2020) make a good approach to it. The research between 1995 and 2017 focused mainly on generic waste management models. However, packaging materials, which in the beginning had only a few papers on them, have been ranking up positions. In the research analysed from 2016 to 2017, they were the third material with more papers on it. In second it came the WEEE articles. The generic models for MSW networks come in first.

Concerning the objective function, van Engeland et al. (2020) says that 90% of the models developed in this area, in general, were single objective models. In two-thirds of those, the objective function is aimed at minimizing the cost. Then, the second most developed objective was maximizing revenue. In addition, 61% of the papers analysed by it consider only cost disregarding environmental issues.

The papers on this topic are mainly all cost-based single objective models. However, some of them consider inside the cost function the environmental or social concerns are converted into the same unit as cost (van Engeland et al., 2020).

Although there is a trend in these models, there are a large variety of approaches and nuances. In the next subsection, articles are going to be analysed deeply in order to conclude which similarities and differences exist between network design models for reverse logistics and this work's model.

3.3.2 Network Design Models

In this subsection, an overview of articles on network design modelling for waste management is going to be described.

The literature on network design concerning DRS for glass can be seen as scarce. However, as mentioned before, there are several models already developed for other almost identical networks such as for WEEE or MSW that resemble the network that this work is aiming to create.

The articles that will follow were selected from relevant scientific journals and also had a considerable number of citations. The primal idea was to have more recent articles than older ones although it was difficult. The search for articles had mainly four requirements to limit the search to models that will, in fact, help further the development of this work. The first requirement was that only single objective and deterministic MILP models were considered. The second was that closed-loop and forward-reverse models were not included since this work model will not consider this kind of network. The third requirement was related to the product that has to be a certain kind of waste. Finally, the fourth was that only models with strategic and some tactical variables were considered such as facilities locations and flows allocations. Models including high-level inventory and freight planning were also considered.

With the goal of diversifying the models within the requirements, a selection of 13 different models was found. The articles were assessed according to the type of waste treated, the type of objective function, the decision variables that constituted the model, the number of products dealt with, and the number of time periods considered. Table 9 shows the classification made and the confrontation with this work goal.

Table 9 - Network Design Article Classification

		Objective		Decision Variables						Number of Products		Time Periods	
Author	Type of waste	Mimize Cost	Maximize Profit	Facilities Location	Facilites Dimension	Inventory Levels	Flow Allocation	Unsatisfeid Collection	Freight Decisions	One	Multi	One	Multi
(Badran & El-Haggar, 2006)	MSW	*		*			*			*		*	
(Emek & Kara, 2007)	Medical Hazardous	*		*			*				*	*	
(Gomes et al., 2011)	WEEE	*		*		*	*	*	*		*		*
(Mahmoudzadeh et al., 2013)	ELV	*		*	*		*			*		*	
(Kilic et al., 2015)	WEEE	*		*		*	*				*	*	
(Demirel et al., 2016)	ELV	*		*			*				*		*
(Lee et al., 2016)	MSW	*		*			*		*	*		*	
(Banguera et al., 2018)	Tires	*		*			*	*			*		
(Garibay-Rodriguez et al., 2018)	MSW	*			*		*				*		*
(Rathore & Sarmah, 2019)	MSW	*		*			*				*	*	
(Tirkolaee et al., 2020)	MSW	*		*			*	*			*		*
(Shafiee Roudbari et al., 2021)	General		*	*			*				*	*	
(Shaban et al., 2022)	MSW	*		*			*		*	*		*	
This Work	Glass Bottles	*		*	*	*	*				*		*

Within the selection made, concerning the objective function, all works consider cost minimization except one that aims at maximizing profit (Shafiee Roudbari et al., 2021) which has as its one main goal to consider the sale of output materials to the market thus the profit function. As mentioned before, cost minimization functions are more prevalent among other objectives (van Engeland et al., 2020).

Concerning the decisions involved, the works differ although all present the flow allocation parameters. In terms of facility location decisions, all perform these decisions for facilities in their networks, except one model analysed which only dimensions facilities in the long-term (Garibay-Rodriguez et al., 2018). There is one more work that selects waste scrap yards locations and dimensions its capacities in a single interval in time (Mahmoudzadeh et al., 2013).

There are three works that implemented high-level inventory management decisions. In the case of Gomes et al. (2011) work, the decision to hold inventory in sorting centres arises to allow possible economies of scale in outbound transportation.

Another interesting decision in similar works is the uncollected amount decision. There are some works that take this into account the option for the collection system to pay a penalty fee instead of not collecting is a possibility. The case of the network design to collect tires in Chile was an example of it where the authors modelled different scenarios where the penalty fee changed yielding the decision of not collecting the waste (Banguera et al., 2018). The same decision was modelled in the work of Gomes et al. (2011). In this work, this was not considered since this decision is not possible in the real context.

Freight decisions concern generally the number of transports needed to fulfil a flow's amount. In the case of Shaban et al. (2022), the determination of how many trucks will be allocated to a certain entity is the decision. A different application of freight planning can be seen in Gomes et al., (2011) where the number of freights necessary to carry the flow amount between two entities is determined.

The large majority of the works observed consider multi-product. The product can be the same but is dealt with in a different way or has different states along the logistics chain, for example, in the case of Tires where there are distinctions in tire sizes (Banguera et al., 2018). This will be the case in this work where the same product (bottles), can be either shredded or as a whole. Moreover, there are cases where there are different products to deal with which is usually the case of, for example, WEEE networks (Gomes et al., 2011; Kilic et al., 2015).

Regarding different time spans, the works analysed vary significantly in the number of time periods, therefore, they were classified as single- or multi-period. Multi-period analysis can be useful when, for example, there is variability in the parameters over time (Gomes et al., 2011; Tirkolaee et al., 2020). Also, when assessing the investment return and revenues, for example, of new landfill facilities construction, it is important to consider this effect (Garibay-Rodriguez et al., 2018).

In terms of modelling, there is one other thing to refer to. There are works' formulations that consider different decision variables according to the number of flows existing in the problems. However, there is one modelling approach for all the flows as one unique variable between subsets of entities (Gomes et al., 2011). This later technique will be also used in this work. Furthermore, Gomes et al. (2011) have a relevant constraint that will also be added to this work. It is the maximum distance imposed between collection points and sorting centres flows.

In conclusion, several works were selected and similarities were found between them and this work. One of the most relevant articles found was written by Gomes et al. (2011) due to the high resemblance in terms of decisions made. Next, the Chapter's main conclusions concerning the literature reviewed will be presented.

3.4 Chapter Conclusions

In this Chapter, the focus was to analyse the literature on several topics that are related to the main topic of this work – the strategic network design modelling and planning of a DRS solution for glass beverage packaging waste.

The Chapter started with a brief analysis of the reverse logistics topic. The main conclusions taken from it were that reverse logistics is a rising research area due to several factors. Stickier policies commonly lead to innovative ways of reducing waste and costs or increasing efficiency. In addition, it is clear that it is a very broader topic that is still in development.

Concerning the DRS schemes literature, the study was the most extensive. All the articles on the DRS topic since 2013 were critically analysed. The literature mainly focuses on Beverage Packaging and WEEE case studies. Most of the articles focus on the efficiency of recycling and collection and comparisons between systems and approaches to waste management.

The main and most relevant research gap found was that there is no related research with network design applied to the DRS and also that there are no academic references to Portugal which plans to implement the system in the near future. This is a major conclusion that justifies, even more, the need for this work development.

In order to find a base to build the model for this future DRS network, reverse logistics applied to waste management literature was explored. Several resemblances between this work's objective and the reverse logistics models were found and analysed. The articles were classified accordingly and more conclusions arose from them.

Keeping in mind the reverse logistics models applied to waste management studied in this Chapter, this work's model formulation will be developed in the next one.

Chapter 4 – Model Design

In this Chapter, the mathematical model will be presented. This model will be used to design and plan the optimal reverse logistics network for the glass DRS collection.

Section 4.1. introduces a brief characterization of this system's functioning, where the main entities and flows are identified. Then, in section 4.2. all the detailed mathematical formulations will be developed. Finally, section 4.3. presents a conclusion to the Chapter.

4.1 Portuguese Glass DRS Characterization

In this section, the Portuguese DRS logistics scheme will be characterised for a deep understanding of the model. As expected, all the DRS have different nuances that influence the way a system works. Therefore, a complete characterization is important before building a mathematical model. This characterization will follow Chapter 2 characterization although focusing in more detail on the reverse logistics process rather than on a full overview of it.

Starting with the post-consumption of the beverage, there are two main paths that glass bottles may take depending on the type of collection – either the bottle can be admitted in the system through automated collection or by manual collection. These two collection types serve different types of establishments. Both the HORECA and Retail sectors can feed the two collection methods. However, in this model, the only sector that will result in some automated collection will be Retail.

These methods of collection will also influence the following logistics processes and operations performed. With the use of the automated collection through RVMs, the system will automatically count the bottles and break the glass into a dedicated reservoir leaving no place for mistakes or fraud in the counting process hence, moving straight directly to Warehouses. As for the manual collection, the glass cannot be shredded in place since the amount can be miscounted or in duplicate. Therefore, after being placed in a Warehouse (as one piece), the bottles have to move to a Counting Centre facility for counting clearance. Then, the bottles are able to be shredded for economic reasons of storage and transportation onwards. The costs of the machinery used in Counting Centres are significantly expensive and hence need to be taken into consideration. The counting operation (both made by RVMs or Counting Centres) will be implemented because it will dictate the RHF paid to the collection place entity to make up either for having supported the costs of installation of an RVM or having assigned employees to the task of collection.

After the bottles are shredded and placed either in Warehouses or Counting Centres, they are sold by the system's operator to Recycling facilities. In addition, the Recycling facilities have already a defined location that will not be possible to change due to the fact that they are independent entities of the system. Also, the

Recycling facilities will have no limit constraints on the acceptance of recycled glass which will be an assumption of this work.

Figure 7 represents a visual approach to the scheme described above. It is possible to identify the different types of entities that are involved in the process (although some are out of the system's boundaries). The arrows' colours show the product state which can be shredded (blue arrows) or in one piece (green arrows). Note that, in the Counting Centres, the arrow input is green and it changes to blue in the output as explained above. The process between the sale, which is when the shredded bottles are sold to "Recycling facilities and packaging industry" to the part where the recycled bottles arrive at the "Beverage producers" is simplified and represents a simpler reality. As they are processes outside of the system's boundaries and, thus, out of the scope of the model, this part was not fully considered and was abbreviated.

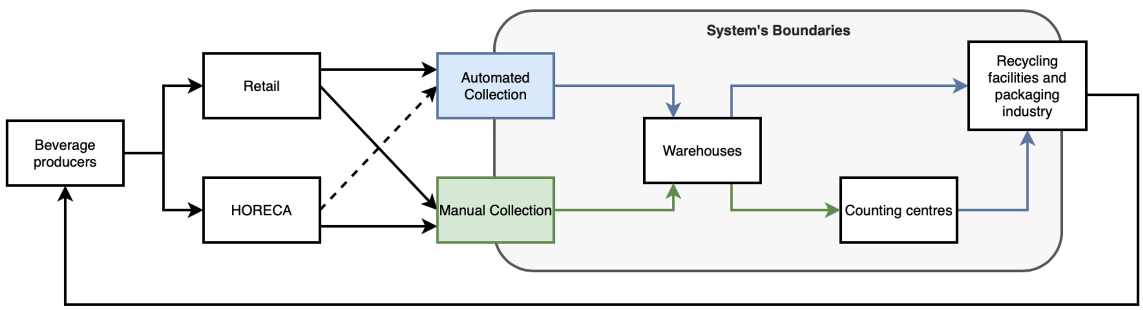

Figure 7 - DRS Flows Scheme (Blue: Shreded Glass, Green:Whole Bottles)

To conclude, in this section the characterization of the glass DRS scheme was clarified. It is important to highlight that the two different collection methods will influence the following operations, movements and costs of the system. In the next Chapter, the goals of the model will be clearly defined.

4.2 Mathematical Formulation

In this section, the model's mathematical formulation is going to be explained. To start, the three core decisions that this work is aiming to achieve are:

- Facilities placement (Warehouses and Counting Centres) given a set of potential locations;
- Allocation of mass flows between entities, considering some context restrictions;
- Periodical inventory quantities that can be held in the facilities.

Concerning the objective, the model processes the strategic-tactical decisions taking into account the minimization of costs such as:

- Transportation costs which are given by the product between flow amount and the cost per kilometre per distance travelled
- Inventory holding costs that are calculated by the product between the amount held in inventory and the inventory holding costs.
- Facilities costs which are constituted by fixed and operational costs.
- Central Administration Costs
- Market sales income (added to the function in the negative way)

In addition, there are other costs and incomes that, although not dependent on the decision variables, they are part of the total system's objective value. They are the RHF and, the uncollected deposits income.

A MILP formulation will be developed below. After the main model objectives were presented, the model formulation will be shown. This section starts by presenting the sets, the parameters, and the decision variables, then, it presents the constraints, and finally the objective function.

1.1.1 Sets

In this model, there are four groups of sets that are relevant to the problem: M for the entities (Municipalities), T for the time periods and, P for product states. Consider the following indexes:

$\mathrm{i}, \mathrm{j} \in \mathrm{M}$ as Municipalities

$t \in T$ as time periods

$p, \bar{p} \in P$ as product states

Entities

The main plot of entities that will be presented is constituted of Municipalities which will be the main building block of the model. Then, facilities such as Warehouses, Counting Centres, and recycling plants must be placed within Municipalities. Therefore, the M set can be split into four main subsets:

N_m as the Municipalities locations

N_w as the potential Warehouse locations, $i \in N_w \subset M$

N_c as the potential Counting Centres locations, $i \in N_c \subset M$

N_r as the Recyclers locations, $i \in N_r \subset M$

Product states

There are two different types of collection that originate two different product states along the chain: Either the bottles are shredded or remain as a whole. These states will influence the path that the bottle takes along the chain. Thus, two different subsets were created: $P_s \in P$ and $P_w \in P$. Note that $P_s \cap P_w = \emptyset$.

P_s represents the bottles obtained through the automated collection and, therefore, are shredded.

P_w represents the bottles obtained through the manual collection and, therefore, remain as a whole.

1.1.2 Parameters

b_{itp}	amount of bottles to collect in Municipality i over the time period t for product state p (tonnes)
d_{ij}	distance between Municipality i and Municipality j in (km)
g^w	Warehouse operational cost per tonne processed (€/tonne)
g^c	Counting Centre operational cost per tonne processed (€/tonne)
m_i^w	Warehouse fixed costs in Municipality i (€)
m_i^c	Counting Centre fixed costs in Municipality i (€)
v	transportation cost per km per tonne (€/km.tonne)
ϕ_t	the desired return rate in time period t
i_p^w	periodical Warehouse inventory holding cost for product state p (€/tonne)
i^c	periodical Counting Centre inventory holding cost per unit (€/tonne)
s^w, p^w	periodical Warehouse storage and processing capacity (tonnes)
$s^c,\ p^c$	periodical Counting Centre storage and processing capacity (tonnes)
μ	market selling price per tonne (€/tonne)
σ	volume ratio between product states
α	central administrative costs in percentage
r_p	RHF for product state p (€/tonne)
β	maximum distance allowed between Municipalities and Warehouses (km)

1.1.3 Decision Variables

Positive variables

X_{ijtp} number of bottles transported from entity i to entity j in the time period t in product state p

Wh_{itp} inventory held in Warehouse i in the period t in product state p

Ch_{it} inventory held in Counting Centre i in the period t

Integer variables

Wb_i Warehouse i opening variable (=0 if closed, >0 if open)

Cb_i Counting Centre i opening state (=0 if closed, >0 if open)

1.1.4 Constraints

Collection requirements

Each Municipality has a certain amount of bottles to collect through manual and automated collection taking into account the return rate defined. This collection constraint assures that the collection for both product states is made and the quantity is all transferred to Warehouses.

$$\sum_{j \in N_w} X_{ijtp} = b_{itp} * \phi_t, \qquad i \in M \ \wedge \ t \in T \ \wedge p \in P$$

(Eq. 1)

Warehouse mass balance

Concerning the Warehouses, the bottles will be transferred there after the collection is made. According to the product state, the bottles can be transferred to Recycling facilities or Counting Centres after. In addition, in order to explore possible economies of scale in transportation, it is allowed for Warehouses to store bottles in inventory over time periods.

The first constraint has the purpose of initializing the mass balance considering the inventory in the first period to be null.

$$Wh_{itp} = 0 \,, \qquad i \in N_w \ \wedge \ t = 0 \ \wedge \ p \in P$$

(Eq. 2)

$$\sum_{i \in N_m} X_{ijtp} + Wh_{j,t-1,p} = \sum_{i \in N_r} X_{jitp} + Wh_{jtp}\,, \qquad j \in N_w \wedge (t > 0) \in T \wedge p \in P_s$$

(Eq. 3)

$$\sum_{i \in N_m} X_{ijtp} + Wh_{j,t-1,p} = \sum_{i \in N_c} X_{jitp} + Wh_{jtp}\,, \qquad j \in N_w \wedge (t > 0) \in T \wedge p \in P_w$$

(Eq. 4)

Counting Centre mass balance

The Counting Centre mass balance resembles the Warehouse mass balance. However, in the Counting Centre, the product state changes meaning that the state of the entry flow is different from the one which leaves.

$$Ch_{it} = 0\,, \qquad i \in N_c \wedge t = 0$$

(Eq. 5)

$$\sum_{i \in N_w} \sum_{p \in P_w} X_{ijtp} + Ch_{j,t-1} = \sum_{i \in N_r} \sum_{p \in P_s} X_{jitp} + Ch_{jt}\,, \qquad j \in N_c \wedge (t > 0) \in T$$

(Eq. 6)

Processing capacity and opening decision

These constraints are needed in order to limit the Warehouse and Counting Centre flows to a limited capacity for processing and storage in a certain time period. The processing capacity is the capacity for all the flows (entry and exit) and also holding. These constrains will also dictate that only opened facilities (binary = 1) will be allowed to have flows.

$$\sum_{i \in N_m} \sum_{p \in P} X_{ijtp} + \sum_{p \in P} Wh_{jtp} \le p^w * Wb_j\,, \qquad j \in N_w \wedge t \in T$$

(Eq. 7)

$$\sum_{i \in N_w} \sum_{p \in P} X_{ijtp} + Ch_{jt} \le p^c * Cb_j\,, \qquad j \in N_c \wedge t \in T$$

(Eq. 8)

Inventory holding capacity

The inventory holding capacity constraints for Warehouses and Counting Centres limit the storage space to a certain capacity. Warehouses can store both product states that have different storage requirements (i.e. different volumes) hence, there is a conversion ratio to convert the two product states into the same storage units of weight.

$$\sum_{p\in P_w} Wh_{itp} + \sum_{p\in P_c} Wh_{itp} * \sigma \ \leq s^w * Wb_j \,, \qquad i \in N_w \ \wedge t \in T$$

(Eq. 9)

$$Ch_{it} \leq s^c * Cb_j \,, \qquad i \in N_c \ \wedge t \in T$$

(Eq. 10)

Maximum Reach

In the flows between the collection in the Municipalities and the Warehouses, there is a restriction that imposes a maximum distance allowed between the two entities.

$$\begin{cases} X_{ijtp} = 0\,, & d_{ij} > \beta \\ X_{ijtp} \geq 0\,, & otherwise \end{cases}, \qquad i \in N_m \ \wedge j \in N_w \ \wedge t \in T \ \wedge p \in P$$

(Eq. 11)

1.1.5 Objective Function

In this model, there is one objective function that combines different types of costs and types of incomes which are detailed below. Note that the Retail Handling Fee cost and the Uncollected Deposits are constants in the model thus, they are only part of the formulation to illustrate how they are calculated although they are not optimized.

$$\begin{aligned} Objective = {} & Transportation\ Costs + Warehouse\ Fixed\ Costs + Warehouse\ Operational\ Costs \\ & + Counting\ Centre\ Fixed\ Costs + Counting\ Centre\ Operational\ Costs \\ & + Warehouse\ Inventory\ Costs + Counting\ Centre\ Inventory\ Costs \\ & + Retail\ Handling\ Fee\ Costs + Central\ Administration\ Costs - Market\ Sales\ Income \\ & - Uncollected\ Deposits\ Income \end{aligned}$$

(Eq. 12)

Which can be translated into the mathematical formulation below:

$$\begin{aligned} Objective = {} & \sum_{i\in N}\sum_{j\in N}\sum_{t\in T}\sum_{p\in P}(X_{ijtp} * d_{ij} * v) + \sum_{i\in N_w}(Wb_i * m_i^w) + \sum_{i\in N_w}\sum_{j\in(N_c\cup N_r)}\sum_{t\in T}\sum_{p\in P}(X_{ijtp} * g^w) \\ & + \sum_{i\in N_c}(Cb_i * m_i^c) + \sum_{i\in N_c}\sum_{j\in N_r}\sum_{t\in T}\sum_{p\in P}(X_{ijtp} * g^c) + \sum_{i\in N_w}\sum_{t\in T}\sum_{p\in P}(Wh_{itp} * i_p^w) + \sum_{i\in N_c}\sum_{t\in T}(Ch_{it} * i^c) \\ & + \sum_{i\in N}\sum_{t\in T}\sum_{p\in P}\left(b_{itp} * r_p\right) - \left(\sum_{i\in(N_w\cup N_c)}\sum_{j\in N_r}\sum_{t\in T}\sum_{p\in P}(X_{ijtp} * \mu) + \sum_{i\in N}\sum_{t\in T}\sum_{p\in P}\left(b_{itp} * (1-\phi_t)\right)\right) * (1 \\ & - \alpha) \end{aligned}$$

(Eq. 13)

4.3 Chapter Conclusions

In this Chapter, the system was characterized deeply, and the mathematical formulation was shown.

In the system's characterization, all the nuances and requirements of the DRS network were analysed. One key issue that the formulation will answer, is the different existing collection methods that will influence the path that the glass bottle may take throughout the logistics chain. On one hand, if the bottles are collected manually, they are required to have a counting clearance in one Counting Centre facility. On the other hand, if bottles are collected by automated collection, which means through an RVM, the counting was already made and the bottles follow from the Warehouses directly to the Recyclers.

The mathematical formulation that will be used to answer this work's purpose was developed. The purpose was to build a mathematical representation of a strategic network design and planning problem for the implementation of a DRS network. This model includes three decisions which are the facilities location selection, the flows allocations between entities and, the inventory level in each facility.

Several constraints modelled the system's requirements such as the waste collection fulfilment, the mass balance in the entities, the maximum processing capacity, the maximum storage capacity and, the maximum distance between Municipalities and Warehouses.

Finally, the objective function was shown in which all the model costs were considered in order to have a total system cost as an output. The model's objective function is a minimization objective.

In the next Chapter, the data to be used when applying the model to the Portuguese DRS context will be characterised.

Chapter 5 – Data Treatment

The purpose of this Chapter is to explain the data sourcing and clarify assumptions made to achieve the parameters necessary as input data to the model developed in Chapter 4 when applied to the DSR Portuguese context. Section 5.1. develops all the data treatment parameters and explains all the assumptions made. Then, Section 5.2. focuses on presenting the methods for selecting potential locations for the Warehouses and Counting Centres. Finally, section 5.3. will conclude the Chapter.

5.1 Data Treatment

The data treatment is important to be explained since some of the data needed for the model was not plainly available in literature or other sources needing first some treatment. The estimations are split between categories of the same group of parameters.

5.1.1 Collection Related (Demand)

The collection was the parameter that implied more treatment to be found. To obtain a value for the mass of bottles to be collected, several auxiliary calculations were needed taking the steps schematized in Figure 8. The explanation of each data point will be made next.

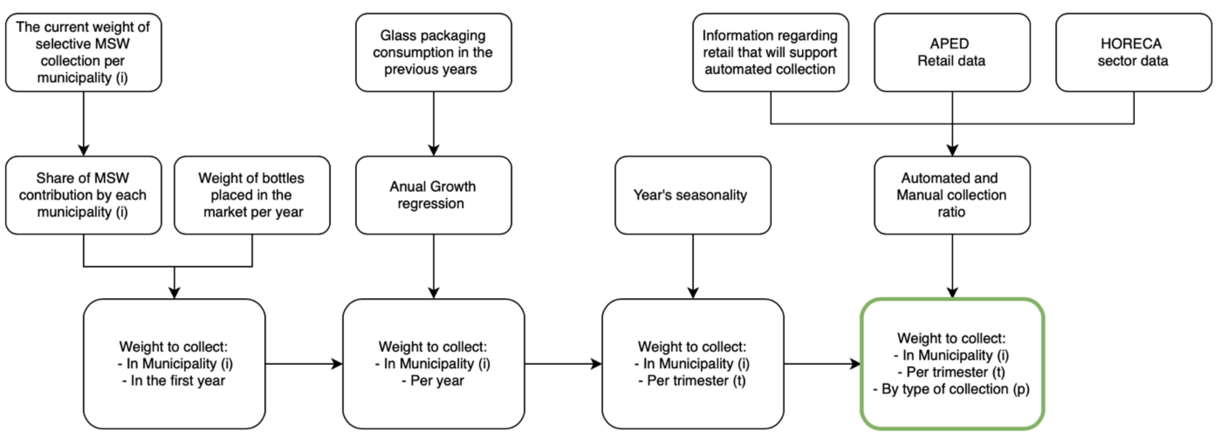

Figure 8 - Steps to Calculate the Weight to Collect

Weight of bottles placed in the market per year

This data is the first one needed to begin the computation and achieve the final result. The weight of glass beverage packaging included in the DRS placed in the market is shown in Table 2 in Chapter 2. The value is 234,600 tonnes.

Weight to collect in a Municipality per year

To perform the splitting of the total weight of bottles placed in the market among Municipalities, a share of waste contribution per Municipality was calculated. This share came from knowing the value of the selective collection of MSW per Municipality.

Annual growth

The annual growth was computed by taking into account the amount of glass waste produced in Portugal between 2012 and 2019 (*Statistics | Eurostat*, n.d.). Figure 9 shows the trendline obtained which shows that, on average, the consumption per year increased by 0,56 kg per capita which can be translated into a 1,63% per year growth in glass packaging.

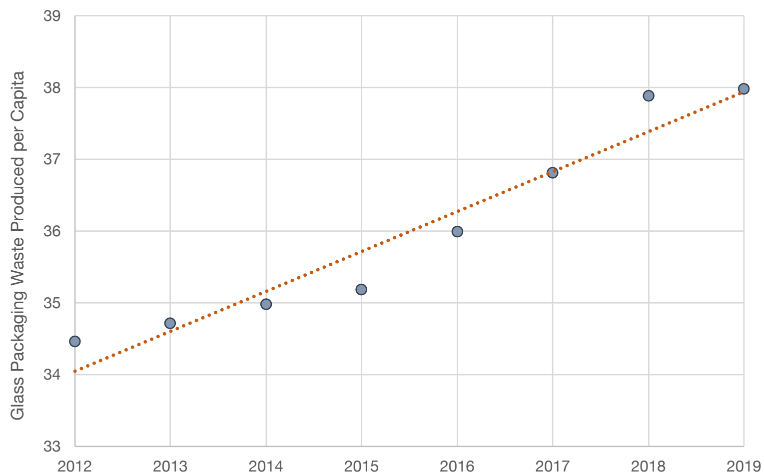

Figure 9 - Glass Waste Produced per Capita in Portugal (kg)

Seasonality

Seasonality is an effect that needs to be taken into consideration since it can impact the number of bottles to collect throughout the year. The seasonality was computed by trimester. Based on a small-scale pilot project in Portugal, it was known that between the first and third trimesters, the volume returned increased. Also, it was observed a 20% decrease between the third and fourth semesters (3Drivers & NOWA, 2020). The trimester contribution for the grand total in a year was then computed and shown in Table 10

Table 10 - Contribution of Each Semester for the Yearly Total

	Trimester 1	Trimester 2	Trimester 3	Trimester 4
Share of each Trimester	24.0%	25.6%	28.0%	22.4%

Automated and Manual collection proportion

As mentioned before, the manual and automated collection are going to influence the path the bottle takes throughout the path. For this reason, the weight of manual and automated collected bottles needs to be estimated.

The first information needed is the contribution of the HORECA sector and the Retail. As it is possible to understand from Table 11, it is inside the Retail stores that it is going to exist the automated collection through RVM.

Table 11 - Weight Contribution of Each Sector and Their Collection Method(s)

Sector	Weight contribution	Collection method(s)
HORECA	41%	Manual
Retail	59%	Manual and Automated

Therefore, the need to look further into the Retail sector is needed. It is known that Retail establishments with more than 1000 m^2 will be able to have an automated collection (3Drivers & NOWA, 2020). Also, there is an exemption of collection in general for Retail establishments with less than 100 m^2. The remaining stores will have manual collection methods alongside the HORECA sector.

Table 12 explores a representation of the stores dimension in Portugal.

Table 12 - Retail Glass Sales Contribution by Area of the Establishment (APED, n.d.)

Area (m^2)	Glass sales (kg/day)	Total contribution	Normalized contribution
<= 100	7 303.30	3%	Exempt
100 - 600	41 289.25	18%	34%
600 - 1000	37 030.40	16%	
1000 - 2000	79 952.40	34%	63%
2000 - 3000	18 609.36	8%	
>= 3000	49 191.30	21%	

Then, by computing the Retail and HORECA contribution it is possible to know the total value for manual and automated collection depicted in Table 13.

Table 13 - Share of Manual and Automated Collection

Collection Method	Adjusted Values
Manual Collection	61.68%
Automated Collection	38.32%

These values will require a mandatory sensibility analysis due to high uncertainty and uncountable numbers in the Retail and HORECA universe.

Return rate

The return rate was sourced in (3Drivers & NOWA, 2020) report where the estimation made took into account similar DRS starting in other countries such as Lithuania where there was an immediate increase in the return rate since the first year of the DRS implementation. In the model, the return rate is an independent parameter from the one represented in Figure 8. This forecast, depicted in Table 14, assumes that the system will be fully implemented and operational already in the first year.

Table 14 - Return Rate Forecast (3Drivers & NOWA, 2020)

	Year 1	Year 2	>Year 3
Return Rate	65%	80%	90%

5.1.2 Transportation

Distance between Municipalities

Taking the Latitude and the Longitude of each Portuguese Municipality, the geometric distance can be easily computed (*Portugal Cities Database | Simplemaps.Com*, n.d.). In this model, only the geometrical distance (straight line) is computed since it is a strategic-level model. Also, it was added the conversion factor between degrees and kilometres is around 111.2 (*Approximate Metric Equivalents for Degrees*, n.d.).

$$Distance(i,j) = 111{,}2 * \sqrt[2]{\left(lat_j - lat_i\right)^2 + \left(lng_j - lng_i\right)^2}$$

(Eq. 14)

Cost per kilometre per tonne

Even though in the real case, the transportation costs will be dictated by the freight fixed costs, the cost per km per tonne is important for the model objective function to work correctly. The value used was based on the work provided by (ERSUC, n.d.) which accounts for 0.094 per km per tonne.

5.1.3 Facilities

The facilities have different data that was needed to be sourced.

Facilities Dimensions and Installation Cost

The first thing to have knowledge of is that, for 10,000 units of bottles processed in a Counting Centre, a space of 54 m^2 is needed to perform those tasks (Schneider et al., 2021). Large facilities of 5,400 m^2 were considered as the standard dimension so that they can process 1,000,000 units of capacity. From this information, several parameters will be developed next.

Concerning the installation, a study reflecting the implementation of the system in Slovakia came to the conclusion that the average installation price for a Counting Centre was about 3,500,000€ (Ministry of Environment of the Slovak Republic, 2018). Then, an estimation was made for the Warehouses. Since these facilities do not require dedicated machinery and non-standard operations, the installation costs were estimated as being around a reasonably 500,000€. Table 15 summarizes these values.

Table 15 - Facilities Dimension and Installation Costs

	Warehouses	Counting Centres
Spaced Used (m^2)	5 400	5 400
Installation Cost (€)	500 000	3 500 000

Capacity

As for the capacity, taking into consideration a facility with 5,400 m^2, and an amount processed of 1,000,000 units, will account for a maximum capacity of around 3,600 tonnes of bottles, taking the average weight of glass bottles. The same capacity was assumed for Warehouses and Counting Centres. However, concerning the product states, whole bottles have a lower density when compared to shredded glass which means that the storage volume is higher for the whole bottles. To answer this issue, the densities of the two products were calculated in order to know how much more space whole bottles occupy than shredded glass. The calculation is explained next.

As for the processing capacity, it seemed reasonable to assume the triple capacity per trimester which just means that three times the number of bottles that can be stored in the facility, can be processed there without being stored.

Lastly, the interest rate is important to measure the value of holding inventory. To measure the inventory holding cost per tonne, a standard interest rate of 20% over the market value of the goods was used for both types of facilities. Table 16 shows the values found.

Table 16 - Facilities Storage, Processing Capacity and Interest Rate

	Warehouses	Counting Centres
Storage Capacity (tonnes)	3 600	3 600
Processing Capacity (tonnes)	10 800	10 800
Interest Rate for Holding Inventory	20%	20%

Average Bottle Weight and Density

With the value for the number of units placed in the market and the total weight shown in Table 2, it is possible to determine the average glass bottle weight. It is the division of total weight by the total number of units placed in the market. It accounts for 362 grams per bottle. In addition, Schneider et al. (2021) had the same conclusions with an average weight of 360g. It is possible to infer that, by having two sources delivering almost the same value, this value resembles reality. For the model input, 360 grams will be used.

Concerning the product density, the states will yield different densities. The two values for the densities were found and the following calculations were performed:

A reference value of 1120 kg/m^3 for the density of shredded glass was found (FHWA, n.d.).

The whole bottles density need further calculations. First, the weight and dimensions of a standard plastic carrying box for 24 bottles was found. Then, an estimation was made for the number of carrying boxes that would fit in a cubic meter of space. Taking the average weight of bottles and the weight of a standard carrying box, a density of 183 kg/ m^3 for transporting whole glass bottles was calculated.

Fixed costs

Concerning the fixed costs, they are composed of three costs that do not vary according to the quantity that passes through the facility. They are accounted for each facility open.

$$Fixed\ Cost = Intallation + \ Rent + Labour$$

(Eq. 15)

The installation costs were already given above.

For the rent, the average renting price per m^2 per Municipality was found and, therefore, used to calculate the renting space of the facilities (*Portal Do INE*, n.d.).

As for labour, Schneider et al. (2021) estimated that a Counting Centre required 40 workers to perform the counting operations which can depend on the capacity. The value estimated for the Warehouses was arbitrarily chosen since no reference was found. If in the Counting Centres machinery has to be operated, in Warehouses there is no need to perform other tasks than basic warehousing movements, therefore, 10 employees were found to be a reasonable estimation. With the established yearly minimum wage value for the company (AIPOR, n.d.), it is possible to calculate the labour costs needed in a very straightforward way.

Table 17 - Facilities Fixed Costs

	Warehouses	Counting Centres
Rent	Same for both	
Number of workers	10	40
Annual cost per employee (€)	13 565	13 565
Monthly total labour cost (€)	11 304	45 217

Operational Cost

The cost of utilities, handling operations and spare parts was estimated of being 11% of the installation cost (Table 15) annually (Schneider et al., 2021). By taking this estimation into account and also the facilities' capacity, it is possible to calculate the variable part of costs accordingly. Table 18 shows the deduction. Of the 11% of the installation, which is an annual value, the costs are split by the four semesters. Then, the unitary cost is the value is simply split by the processing capacity (Table 16).

Table 18 - Facilities Operational Costs Calculation

	Warehouses	Counting Centres
11% of the installation cost (€)	55,000	385,000
Cost per tonne processed (€)	1.27	8.21

Lastly, it is important to mention that, while the installation cost is only paid once, the operational cost is paid for each tonne that is processed there. It is measured by the outbound flow of the facilities because it means that the unit has been already processed.

5.1.4 Market Data

Although there are several divergences in the literature regarding the selling price of the shredded glass, the value used is 40€ per tonne (3Drivers & NOWA, 2020). There are some divergences with, for example, the value pointed out by (Schneider et al., 2021) which is 13€ per tonne. The value of 40€ per tonne will be chosen because it concerns a recent year and also is referent to the Portuguese market.

5.1.5 Others

Central administrative costs

These costs are taken into account as a whole representing the needs for the system's administrator central operations, for example, labour, IT systems, infrastructure, or communication. According to (3Drivers & NOWA, 2020), they will represent 2,5% of the Portuguese system's income.

Deposit value per tonne

The Portuguese deposit value is already known and it will be 0,10€ per bottle (3Drivers & NOWA, 2020). Since a tonne represents around 2778 bottles, then the deposit value per tonne is 277,8€.

RHF

The RHF is the fee paid to the Retail and HORECA establishments to cover the costs of the obligation to be part of the DRS (Schneider et al., 2021). This will be one of the major costs of the system. The value paid per bottle in Portugal is planned to be the same for automated and manual collection and it will be 0,04€/bottle (3Drivers & NOWA, 2020).

5.2 Possible Locations Selection

Following the data treatment and parameters development, in this section, the location selection method will be shown. First, the general method for selecting possible locations will be shown. Then, in the two next sections, the set of potential locations for both Warehouses and Counting Centres will be detailed and the final set presented.

Although the main geographical unit in this problem is the Municipality, there will also be a need in the following subsections to cluster the data of Municipalities into larger regions with several purposes that will be explained in the subsections. To proceed with this clustering, instead of using the 18 administrative regions commonly utilized to split the territory of Portugal, the second level of the European system of Nomenclature of Territorial Units for Statistics (NUTS II) was used which divided the territory into 23 economical areas (*Background - NUTS - Nomenclature of Territorial Units for Statistics - Eurostat*, n.d.). Also, several datasets sourced had the data clustered according to the NUTS system hence one more reason to cluster the territory in this way.

The complete set of potential locations for Warehouses, Counting Centres, and defined Recycling facilities is referred to in the Annex.

5.2.1 General Selection Procedures

The primal thing to take into consideration before defining the selection strategy is to study the amount to collect in each Municipality. There are NUTS II regions where glass beverage waste is more prevalent than in others. Namely, the metropolitan area of Porto and Lisbon and the Algarve. Also, it is possible to see the waste concentration closer to the littoral than in the interior of Portugal.

To have an efficient location selection procedure, four types of methods were taken into account and used accordingly for the selection of potential sites:

- Method 1: A minimum and maximum number of potential locations per NUTS II
- Method 2: The sum of the glass waste to collect inside a given circular radius around one Municipality;
- Method 3: The ratio between Method 2 and the average cost of rent per m^2.
- Method 4: Assess strategic Municipalities to fulfil particular network requirements

By using these methods combined, the possible locations were selected accordingly. Next, the selection of potential places for Warehouses and Counting Centres will be developed.

5.2.2 Potential Warehouse Locations Selection

The first step was to define how many locations per NUTS II would be required. For this, the regions were sorted according to the waste generated there. Each NUTS II region would be given one location summing 23 different locations to be then decided locally by the other selection methods. Then, by looking at the cumulative contribution of waste per region represented in Figure 10, it is possible to depict that 7 regions account for 80% of the glass beverage waste generated. For these regions, the selection was carefully performed.

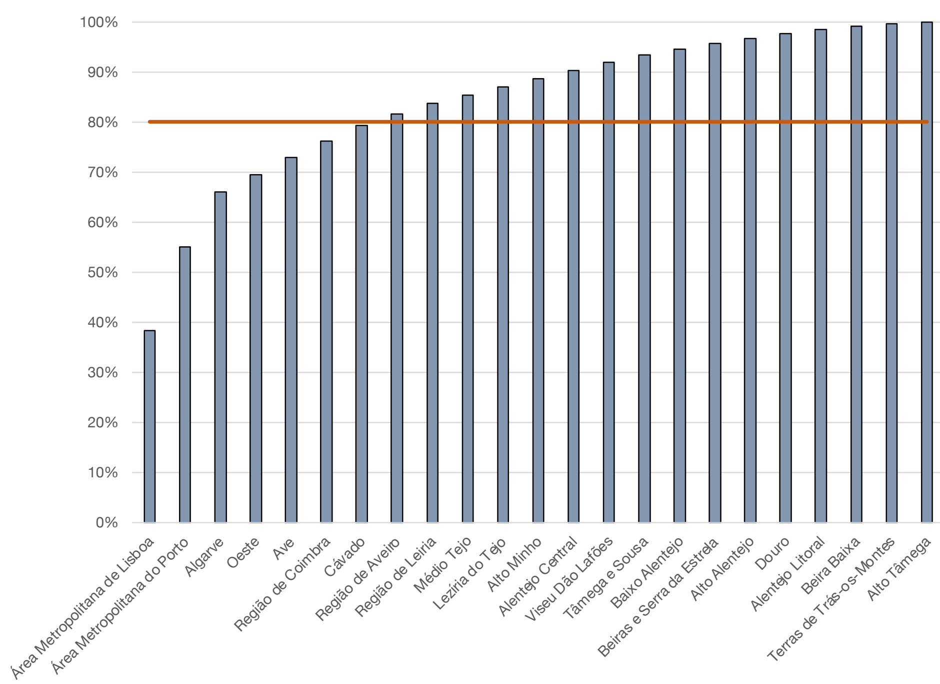

Figure 10 - Cumulative NUTS II Waste Contribution

Then, for the Municipalities selection within the regions, the first step was to compute the sum of the glass waste to collect inside a 100 km circular area around one Municipality. Then, the ratio dividing that sum with the average renting price was computed for all Municipalities. After that, the higher value ratio for each NUTS II area was selected and added to the set. In addition, there were some strategic places added to the set because, although they might not be places ranked higher in the criteria, are important in terms of the logistics panorama in Portugal or will serve the fulfilment of some regional characteristics. Figure 11 represents the final outcome of the selection.

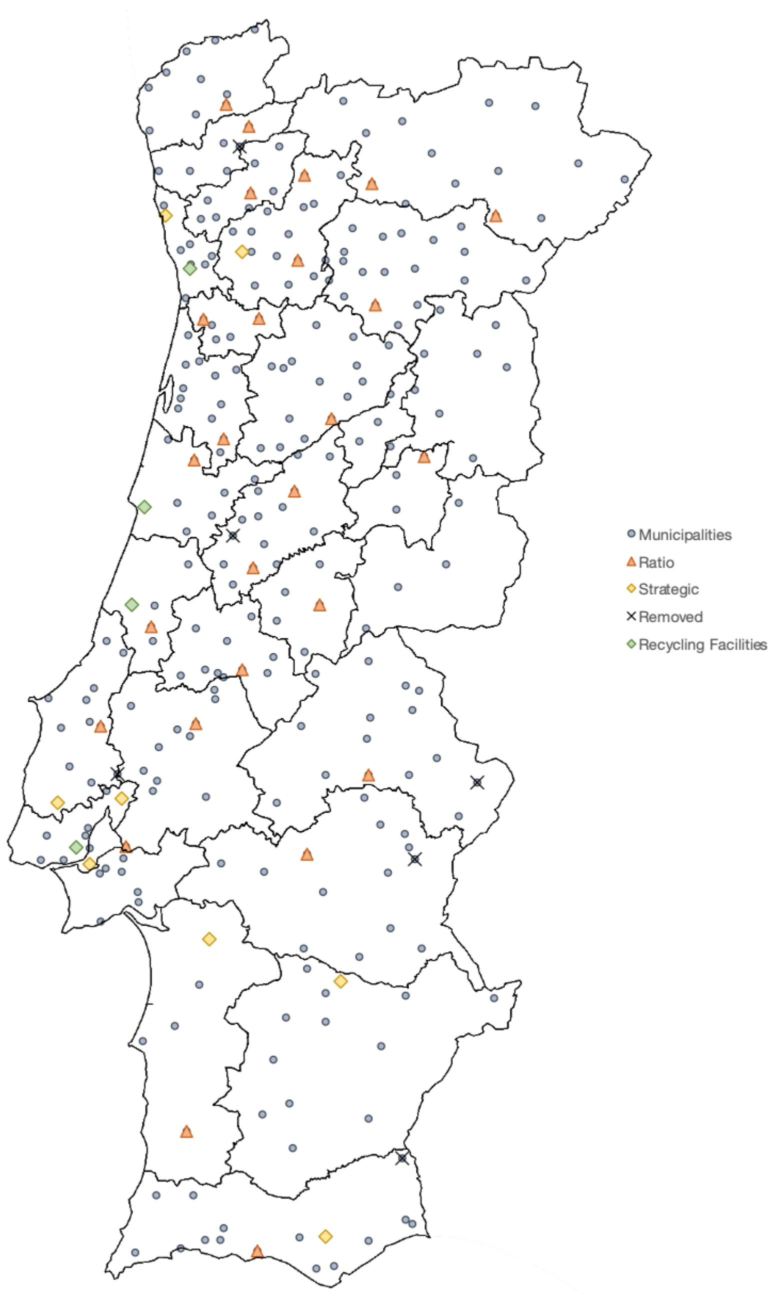

Figure 11 - Warehouse Potential Locations

The network presented in Figure 11, suffered some minor changes as it is possible to identify, for example, the removed locations. Initially, the ratio returned locations of three southern locations close to the Spanish border in remote areas (mainly due to the low average renting price). Those facilities were removed and changed to other Municipalities. The initial set also had some pairs of locations both close to each other such as the Amares facility, which was selected because the region is one of the major contributors, was not only close to the border but also had two neighbour Municipalities with potential places. Thus those were also removed. The strategic places were then added taking into consideration the imposed restriction that the maximum distance between a Municipality and a Warehouse is 100km. Some of those locations had the purpose of fulfilling remote Municipalities.

The set was narrowed to 34 possible locations for Warehouses. In the following section, the same will be described for the Counting Centres.

5.2.3 Potential Counting Centre Locations Selection

The process for selecting potential locations for Counting Centres was slightly different from the method used for selecting Warehouses' potential locations. While Warehouses' flows are directly connected to the Municipalities and have to serve the purpose of aggregating masses and should be distributed along territory, the Counting Centres are in another level inside the logistic chain.

A sum of waste to collect was calculated taking into account a 200km radius. This range made sense since one Counting Centre is expected to serve several Warehouses and a larger area. In addition, the Counting Centres are expected to open in fewer locations due to their significantly higher installation costs than the Warehouse's ones. Then, with the sum of glass waste for each Municipality, a ratio was made in the same way made for the Warehouses to make the selection of locations more efficient in terms of land price. Then, for the most significant NUTS II regions of Portugal, the locations with the best ratio were selected. It was also allowed for regions to have more than one location. Mainly the component was a higher ratio combined with a strategic place serving not only waste-dense areas but also by serving recycling plants in the vicinity. A set of 10 locations was formed and it is represented in Figure 12.

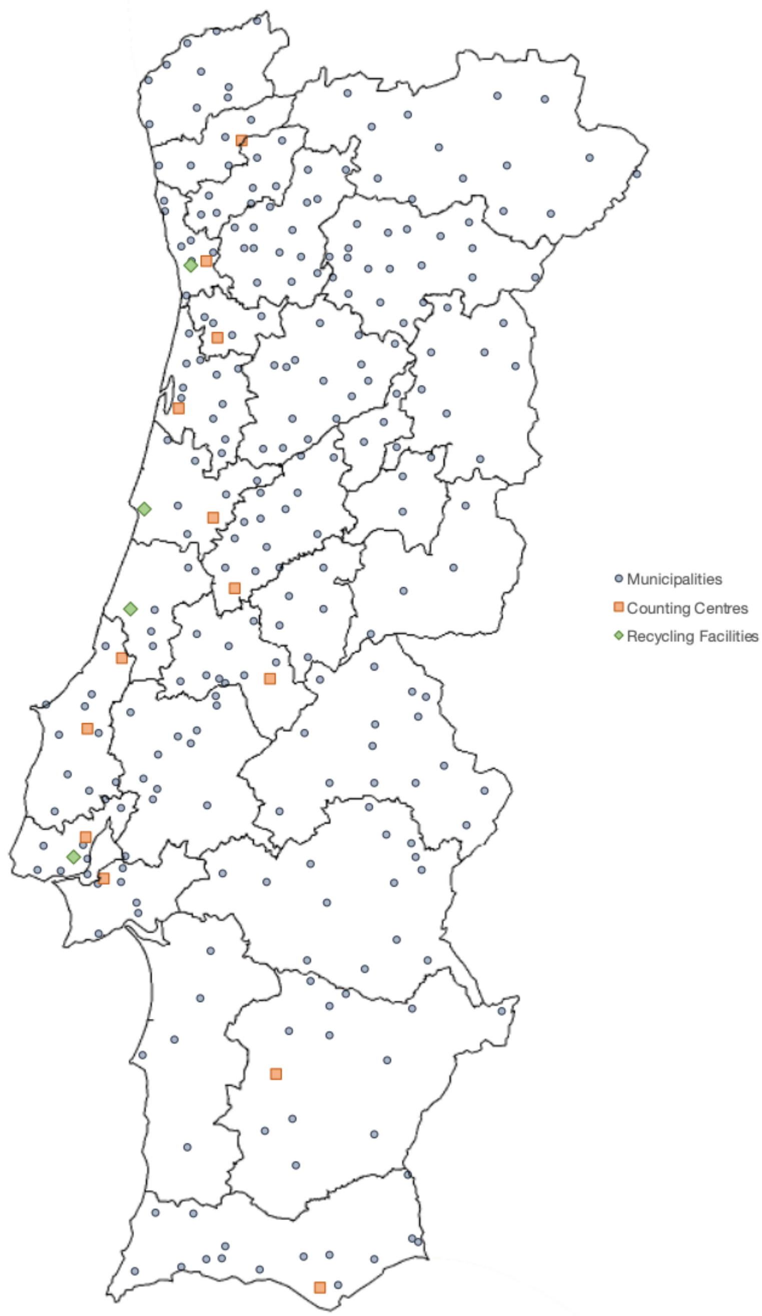

Figure 12 - Counting Centre Potential Locations

5.3 Chapter Conclusions

This Chapter had two key purposes – to present the data sourcing used to estimate the parameters to be used in the Portuguese context and, the set creation of potential locations for Warehouses and Counting Centres.

In the data sourcing section, all the calculations performed the inputs and steps to achieve them were demonstrated. They were grouped between the collection, transportation, facilities, market and others. Information was sourced from official public sources (Portugal and Europe) but also, from articles that were found in the literature and mentioned in Chapter 3. Some estimations and simplifications had to be made for data that was not possible to find. Taking this into account, the next section will perform a sensibility analysis of the parameters that have a higher degree of estimation.

In the location selection, the goal was to select a reasonable set of potential places to host Warehouses and Counting Centres. The working unit is the Municipality, however, the NUTS II regions were also considered to support some decisions The first analysis made, was of the contribution of waste of each region. It was concluded that 7 out of the 23 NUTS II regions contributed 80% of the total glass waste production in Portugal. Those regions were the ones closer to the littoral and around Porto and Lisbon Metropolitan Areas and Algarve.

For the Warehouse selection, there was the need of having a geographically well distributed network thus, one or more locations in each NUTS II region were selected. For this, a ratio between the sum of waste in neighbour Municipalities (in a radius of less than 100km) and the average renting price was used. Adding to this selection, strategic places were added given their importance to the logistics of this network. In the end, a set of 34 locations were considered.

The Counting Centres' potential location selection was, to a certain extent, different. Since the land coverage is not a priority, 10 potential locations close to the areas that had more waste density and with a low average renting price were selected.

In the following Chapter, these data will obtained for the model application into the Portuguese context will be critically analysed in order to deliver solid conclusions.

Chapter 6 – Results Analysis

In this Chapter, the model results are going to be shown and deeply analysed. It is important to critically describe the results and clarify the reasoning behind some of the decisions taken. Section 6.1. and 6.2. will present two scenarios approaches while section 6.3. will show the computational results of the two scenarios. Then, section 6.4. will focus on performing a sensitivity analysis of the most critical variables. Finally, Chapter 6.5. will present the main conclusions of this Chapter.

Throughout this work, several hypotheses were assumed and several approaches are still up for discussion regarding the implementation of the DRS in the Portuguese case. Therefore, the need to study different scenarios is important.

One thing that is important to consider is that, due to the computational effort required, there were some studies that were not considered because they were not executable in a reasonable amount of time. There is a clear trade-off between the computational effort and the complexity of the model. By taking this into consideration, two possible scenarios were considered:

- The baseline scenario is the formulation considering the case that was fully described in Chapter 4. The main inputs will be the ones considered in Chapter 5.
- A second scenario that is a formulation considering the hypothesis of removing the existence of Counting Centres. The inputs still remain the same except for the ones that influence this change.

Each one of these scenarios is relevant and, in the following sections, the scenarios' results will be analysed deeply.

6.1 Scenario 1 – The Baseline Case

This case results from the application of the model presented in Chapter 4 with data presented in Chapter 5. It calculates the facilities' positioning (Warehouses and Counting Centres), flows allocations and also inventory levels in the facilities. The following outcomes were found.

6.1.1 The Network Structure

The network structure obtained is depicted in Figure 13a.

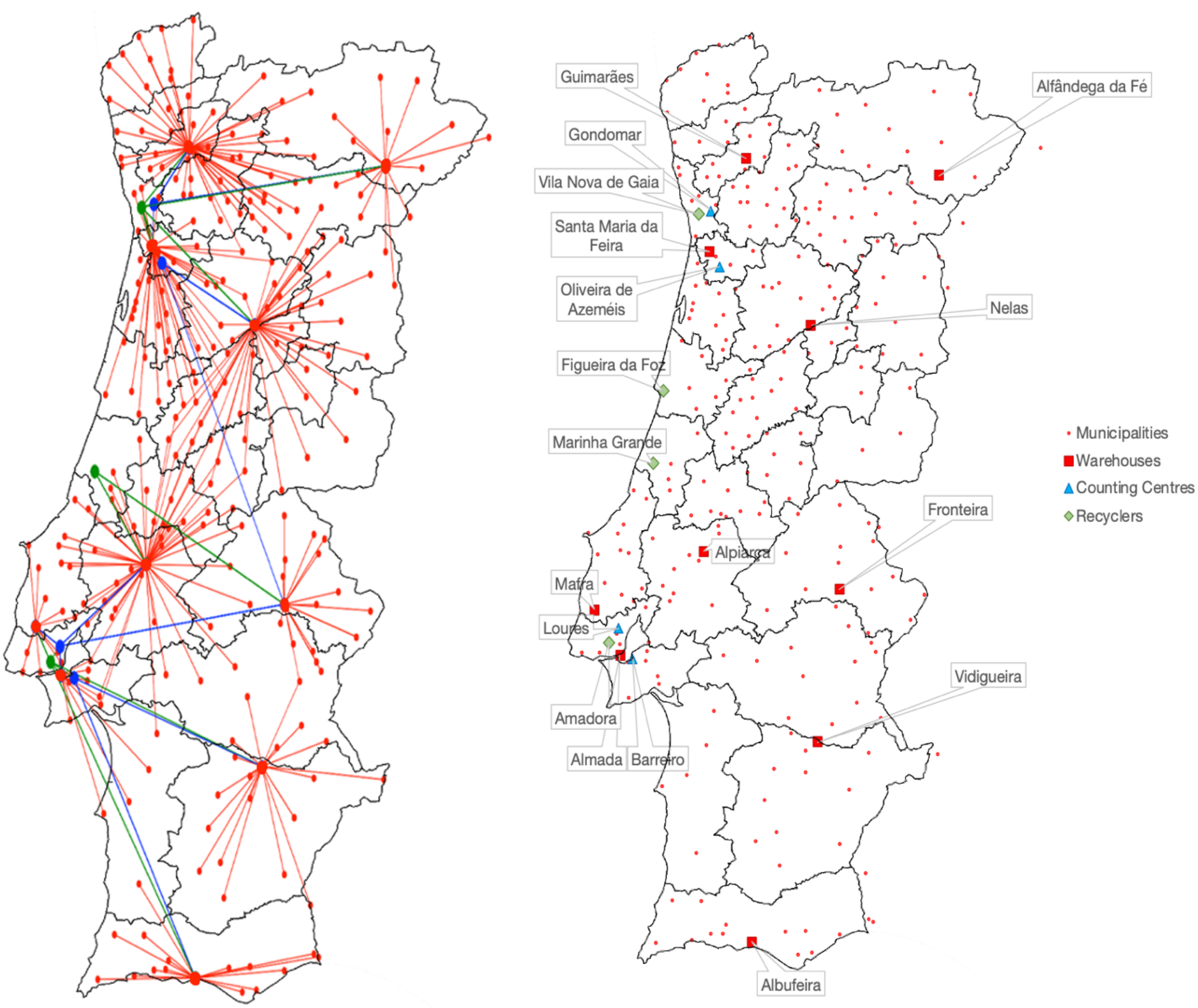

Figure 13 - Network Structure for Scenario 1

In Figure 13b are the selected Warehouses. As it is possible to observe, ten Warehouses were open and are properly distributed on the map. One of the reasons for this distribution is the fact that the formulation imposed a maximum distance constraint of 100 kilometres between Municipalities and Warehouses. In addition, all the waste collection in Municipalities had to be collected

By looking at warehouse processing capacity utilization over time in Figure 14, it is possible to observe, that there are mainly three visible groups of Warehouses. The ones that hit the maximum allowed processing capacity, the ones in the middle and with many variances in the middle and then, the ones that barely have processing (lower than 20% of its capacity).

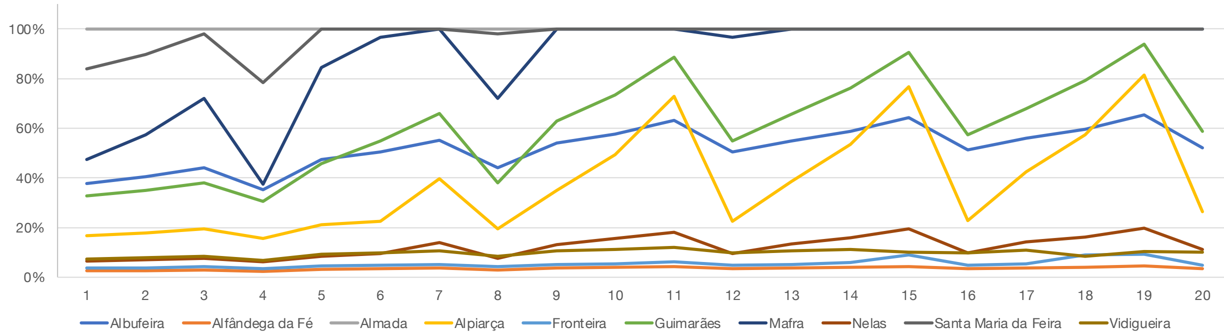

Figure 14 - Warehouse Processing Capacity Usage for Scenario 1

The Warehouses with less than 20% should be explored deeply. If the maximum travelled distance did not exist, those facilities were unlikely to be opened. Although it was not studied a case allowing de decision of not collecting waste in a Municipality in exchange for paying a penalty would help solve this issue. As explained before, this decision was not implemented because, in the real case, this is not allowed.

The Warehouses with peak capacities were all located in places near Lisbon and Porto area, the regions with higher demand. As for the Warehouses only with middle processing capacity usage, either they serve as a capacity extension for Porto and Lisbon regions, or they were placed in areas such as the Algarve (Albufeira Warehouse, see Figure 13a) which the waste of that area represents around 50% of the processing capacity.

In the Counting Centres case, the resulting location is different (see Figure 13b). The maximum travelled distance was not imposed therefore, there was no need to have a well distributed network. Firstly, because the quantities were already previously aggregated in the Warehouses. Then, due to the high installation costs, the network would have been much more expensive and would have been Counting Centres with lower rates of processed waste.

In conclusion four were opened. Two in the Lisbon Metropolitan Area (Barreiro and Loures) and two in Porto Metropolitan Area (Gondomar and Oliveira de Azeméis). In reality, those four locations may have an efficient geographical implementation. Lisbon Metropolitan Area is separated by a river which means that there is a natural obstacle in the transportation of goods between the two sides. The results of positioning resulted in placing the two Warehouses on different sides of the river which ends up being a fitting configuration. The same case happens in the Porto Metropolitan Area where the two Warehouses are placed in Municipalities on different sides of the river.

Concerning the four Counting Centres' processing capacity utilization, Figure 15 presents it along the time.

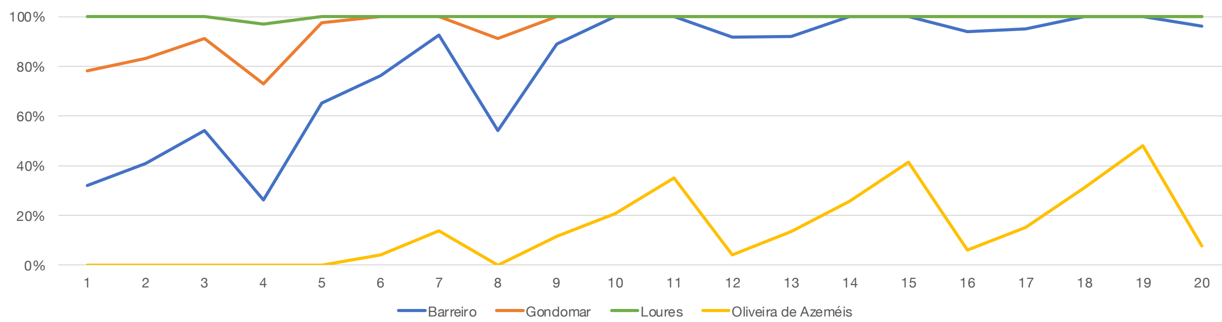

Figure 15 - Counting Centres Processing Capacity Usage for Scenario 1

It is interesting to note that, in each of the regions, one of the Counting Centres starts with a much higher capacity that the other one. In Lisbon Metropolitan Area, the Loures facility starts at its maximum capacity and then the Barreiro one will eventually increase along the yearly defined growth of waste in the system. In Porto Metropolitan Area the same effect is observed in a smaller proportion. The Gondomar facility hits the maximum processing for the first time in time period 6 (one year and a half of the implementation). Then, in the second year, the Oliveira de Azemeis facility opens to fulfil the rising waste to be processed.

Lastly, there was a limitation observed on the inbound flow of Recycling facilities. These facilities were given and they already existed in the network. Another limitation of the model lies in the fact that there was no restriction imposed on the maximum amount of goods transferred to the Recyclers. This means that one of the stations could accept all the waste. Figure 16 shows the waste quantities that were transferred to the Recyclers throughout the time periods.

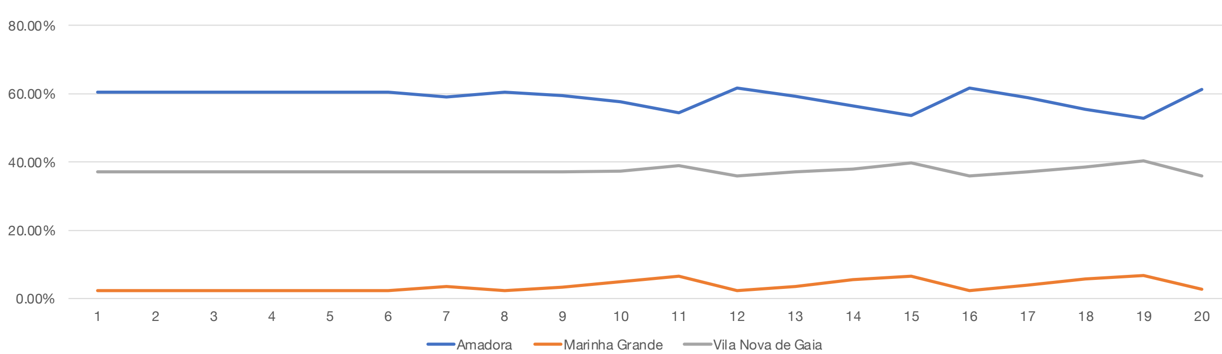

Figure 16 - Total Flow Distribution by Recycler

Among the four existing recycling plants, the waste distribution is very different. There is even one facility, the Figueira da Foz one, that does not receive any quantity. In addition, the Marinha Grande facility receives quantities below 10% of the total which is considerably low. Since the two others are placed in the areas in which there is more beverage waste produced, it is perceivable that the flows are going to be transferred there instead of a farther place.

Concerning inventory levels, they were not significant. Counting Centres inventory remains constantly with a null value. As for the Warehouses, just minor sums in quantities in very particular time periods are observed. It might be related to the inventory holding rate used. The cost of keeping one tonne in inventory is higher than transferring it to a recycler to be sold for a higher quantity.

In general, due to the increase in the amount of waste to collect each year, there is an increase in the usage and inbound flows of all the facilities. This increase is more relevant, especially between the first and second year of activity where the return rate parameter rises considerably. The yearly variability in the inbound flows that can also be observed in every type of facility is mainly due to the trimestral seasonality in the consumption pattern that was initially modelled. The question remains if a significant demand variability can be handled in the real case.

6.1.2 Costs

In this section, the costs and revenues of the baseline case are going to be analysed. The total costs of the system are 163 million and the income would be around 97 million which accounts for a total system cost of 66 million over five years of operation. These values are shown in comparison in Figure 17.

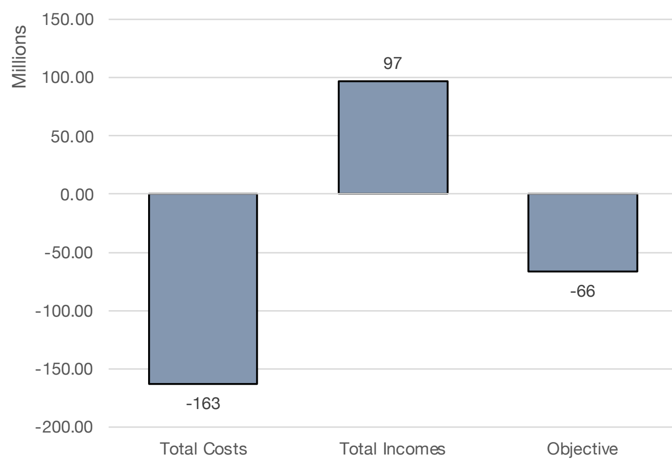

Figure 17 - Costs and Incomes Comparison for Scenario 1

Since the costs are, in absolute terms, the higher contribution, they are going to breakdown by their origins which are shown in Figure 18.

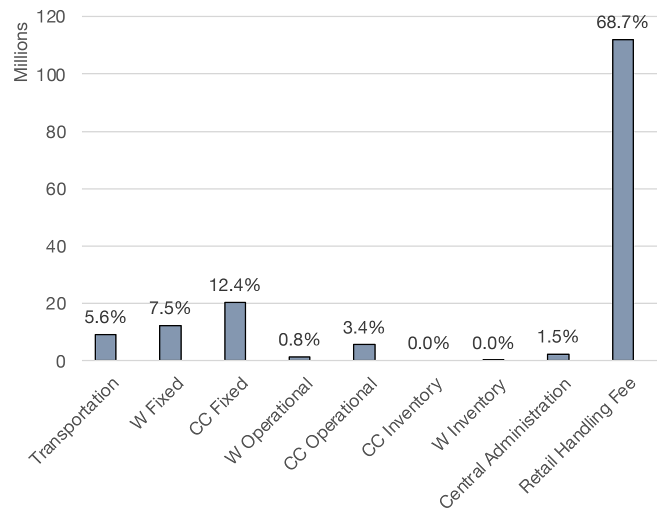

Figure 18 - Cost Structure for Scenario 1

As it is possible to clearly observe, there is one cost that stands out. It is the RHF paid. According to 3Drivers & NOWA (2020), this cost is the higher cost in every DRS excluding only particular cases such as the German system. In the Portuguese case, an estimated RHF of 0.04€ per bottle collected represents around 70% of the total cost of the system. It is important to mention that, this incentive fee was not optimised but only calculated into the model, as stated before. It is related to the number of bottles returned which the logistics do not have control over. One possible solution would be the beforehand negotiation of this fee with the Retail and HORECA sector representatives in order to reduce it. Another would be to pay different amounts for automated and manual collection. As benchmarked in Chapter 2, it is more common for countries to pay different compensations for the different collection methods. Also, by paying a higher amount for the automated than the manual collection, it is created an incentive for the Retail sector to install more RVMs and increase the share of automated collection facilitating the logistics of the whole scheme.

There are other costs that, though not so high as the RHF, are still significant. Those are the installations' fixed costs and the transportation ones. Unlike the RHF, these costs can be optimized. The remaining costs are not significant to the system dimension and do not constitute a problem even though some of them can be optimized through modelling as it was made in this work.

Next, the focus will be on the system’s revenues which can reduce effectively the system’s total costs. The income structure is represented in Figure 19.

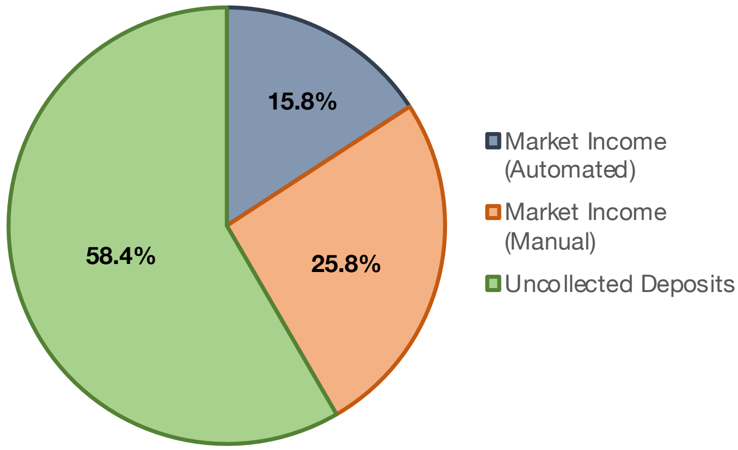

Figure 19 - Income Structure for Scenario 1

Mainly there are two big sources of income in the DRS both represented. The market profits, which are related to the sale of shredded glass to Recyclers and account for 41.6% of the whole income.

Concerning the uncollected deposits, they are the bigger source of income, which is desirable for the system's administrator. However, as mentioned in Chapter 2, this constitutes a backwards incentive to the DRS. Because, on the one hand, the DRS's mission is to collect beverage waste effectively. On the other hand, this source of revenue is desired but only obtained when the system is not completely effective.

In conclusion, costs are higher than incomes. However, observing the total amount for a period of five years, the total needed might be reasonable. Ideally, the system would fund itself. This could happen in two ways, either through the reduction of costs or the increase of revenues. Focusing on the costs, the reduction of the RHF (main cost) would be beneficial as it is going to be explained next. Focusing on the profits, the increase in the uncollected deposits would mean a decrease in the effectiveness of the DRS therefore cannot be considered. The increase in the market selling price would be beneficial although not underneath the DRS control.

There is one last option that this system did not consider. Chapter 2 mentioned three sources of income. The third one was to fund the system through fees that producers would pay to the DRS for every bottle placed in the market. However, it is not clear yet if Portugal is going to implement this fee or not thus, it was not considered in this analysis.

6.1.3 Computational Results

Table 19 details the computational results obtained for this scenario.

Table 19 - Computational Results of Scenario 1

Scenario	Total Variables	Binary Variable	Total Constraints	Number of LP's	CPU's	Gap (%)	Opt.Value
1	3 098 340	47	304 994	22 857 500	15 678	4.76%	66 097 968

6.2 Scenario 2 – Counting Centres Exclusion

This scenario constitutes a more theoretical approach. The purpose of this analysis is to consider the possible cost burden of alleged fraud in comparison to the Counting Centres' cost waiver. To perform this assumption it was considered that all the beverage waste will follow the path of the automated collection and no bottles would be counted.

6.2.1 The Network

As mentioned before, the network flow of this scenario will be simpler than the baseline case, as shown in Figure 20. All the waste follows the same path which means that the waste is collected in the Municipalities and transported to the Warehouses which then follow to the Recyclers.

In comparison to the baseline scenario, only minor changes in the Warehouses' placement were found. There were two changes in the Warehouse positioning. First, in comparison to scenario 1, the Nelas Warehouse closed and was replaced by the Belmonte one. The quantities processed there were reduced slightly. However, this change can be explained by several factors. In scenario 1 Nelas Warehouse was closer to a Counting Centre than Belmonte. Also, although both locations already have a low average renting price, Belmonte has a lower value than Nelas.

In addition to this change, there was one more Warehouse that urges in this scenario which was the Batalha Warehouse. It mainly can be explained by the fact that it was placed close to a recycling facility (Marinha Grande) and serves mostly the area that Alpiarça served in scenario 1.

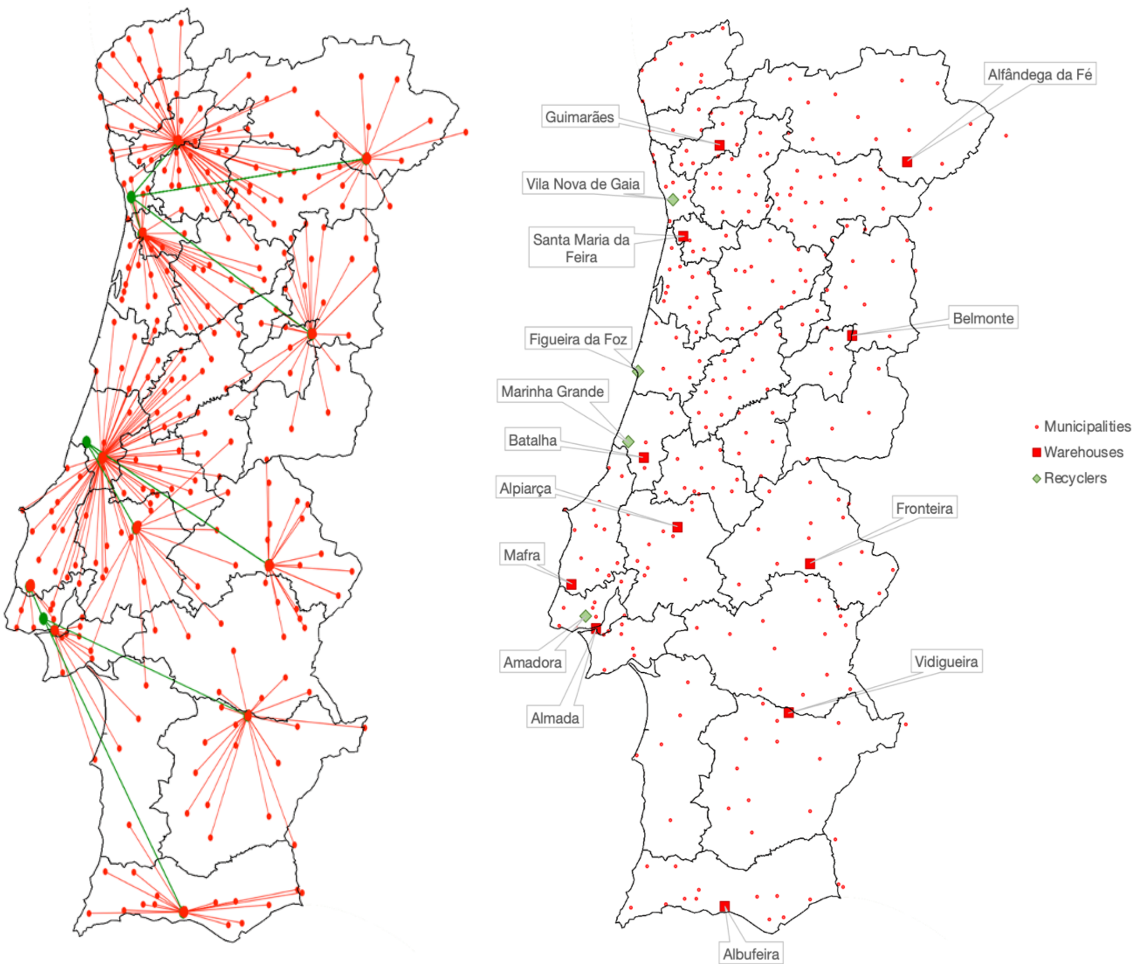

Figure 20 - Network Structure of Scenario 2

Marinha Grande recycling facility started to receive more quantity in this scenario. This happened because the outbound flows of the Alpiarça Warehouse were split. The shredded glass would go to the nearest recycling facility. However, as whole bottles had to be transported to a Counting Centre, the nearest one was in the Lisbon area which then would be transferred to the nearest recycling facility there (Amadora).

Furthermore, one of the Warehouses shifted its location to a closer spot. Due to likely be more efficient in terms of transportation costs which, compared to the other case, would also have to be balanced according to the Counting Centres locations. Another finding is that one extra Warehouse opens.

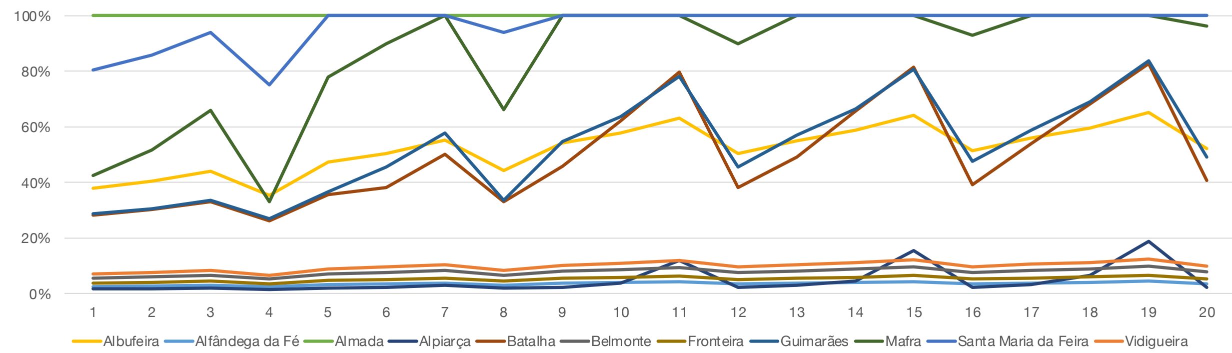

Figure 21 - Warehouse Processing Capacity Usage for Scenario 2

Regarding the Recyclers, the same effect happens. Figueira da Foz recycler does not receive any of the quantity. However, the recycler that, in the first scenario received less quantity is now receiving more (Marinha Grande). This can be explained by the fact that Warehouses within reach can now transfer all the quantity directly there without passing in a Counting Centre (which would be closer to the other Recycling facilities).

To conclude, the presence of Warehouses with low processing volumes appears again. This is still related to the fact that there is an imposed maximum distance between Municipalities and Warehouses. One more Warehouse opens in a location close to the Marinha Grande recycler. That same recycler starts to receive more waste as it is perceivable by looking at the inbound Recyclers flows. Next, the costs of this scenario will be detailed and further analysed.

6.2.2 Costs

The cost structure changes some things that are worth pointing out. First, there are no costs with Counting Centres and related transportation. The cost comparison between scenarios is shown in Figure 22, the RHF costs were excluded because they were the same amount in each scenario. As mentioned before, this fee is not related to the logistics variables. However, the RHT contribution to the total cost grew from around 70% in the first scenario to 80% in this scenario. The uncollected deposits and market sales behave the same way. Hence, all the profits remain the same. Only the cost structure changes.

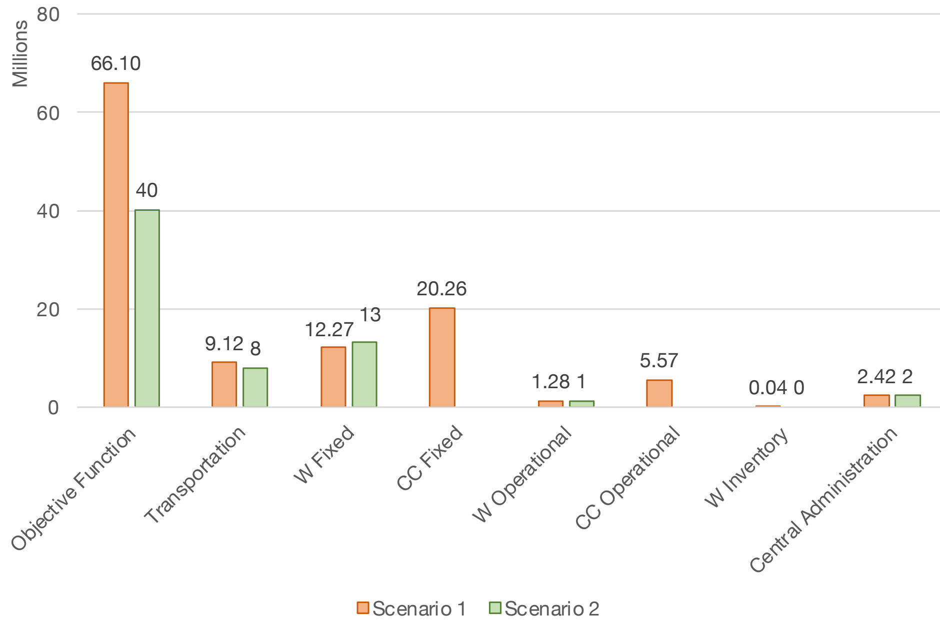

Figure 22 - Cost Structure Comparison of Scenario 1 and 2

Scenario 2 has, in fact, fewer costs. The Counting Centres' costs (fixed and operational) combined, are in general responsible for the reduction in the Objective Function value. In addition, there is an increase in the Warehouses' fixed cost (opening of one more facility) and there is a decrease in the transportation cost.

In conclusion, the waiver in the system's final cost value is around 26 million. However, this scenario would only be possible to consider if the cost of fraud is lower than this waiver. This will be answered in the next subsection.

6.2.3 Accounting Fraud Occurrences

Fraud situations can happen if there is no bottle counting clearance in the process. As explained before, in Retail, when a consumer returns a bottle to an establishment, the deposit fee is paid back to the consumer. Given the number of counts an establishment makes in a time period, the deposit fees are paid back to the Retailer by the system's operator. In addition, the system's administrator will pay the RHF for compensating the burden of collecting bottles. Mistakes might happen in the process of counting which, theoretically, justifies the solution of the Counting Centres' existence. As also mentioned before, the automated collection will shred the glass after it enters the counting machine leaving no space for discrepancies.

Mistakes would not be significant, however, fraud on a larger scale might be. That is what is going to be analysed in this section. This matter is relevant to discuss because there is a cost trade-off to be made between miscounted counts and the inclusion of Counting Centres.

The first question to be analysed is the number of establishments that might be eager to commit fraud.

In the Retail case, there is no incentive for it, in a general way. Firstly, the Retail market is owned mostly by supermarket chains which means that employees would not benefit from committing fraud themselves because they would not benefit from it directly. Looking at the low share of groceries that might have independent owners that would benefit directly from committing fraud, those stores usually are small and have less than 100 m^2. Stores with less than 100 m^2 are excluded from the DRS so, they are not accountable.

Therefore, the only establishments where fraud might happen is in the HORECA sector which represents 41% of the total establishments included in the DRS. Each unit that is miscounted costs the system the value of the deposit value and the RHF which is 0.14€. In tonnes, this accounts for 388.92€. Table 20 analyses the cost impact of existing fraud even on a larger scale.

Table 20 - Fraud Cost Analysis

Fraud Rate	5%	10%	15%	20%	25%
Weight in faud	4 809	9 619	14 428	19 237	24 047
Total Cost of Fraud	1 870 433	3 740 866	5 611 299	7 481 732	9 352 165

Looking at these results, only if even more than 50% of the bottles were wrongly declared is where this solution would break even with the costs of scenario 1. Since it is very unlikely for a system to have a fraud rate higher than 50%, this scenario might be considered and pondered in reality.

6.2.4 Computational Results

Table 21 details the computational results of the second scenario.

Table 21 - Computational Results of Scenario 2

Scenario	Total Variables	Binary Variable	Total Constraints	Number of LP’s	CPU’s	Gap (%)	Opt.Value
2	3 098 340	47	304 994	105 576	115	4.18%	40 168 751

6.3 Sensibility Analysis

The sensibility analysis gives the opportunity of studying several parameters and their impact on the model. It will be performed for the baseline scenario which is the one that needs closer attention since it represents a similar context to what will be the DRS system in Portugal.

The parameters that were chosen to investigate were the ones that gathered one of the two following characteristics. The first is their weight on the costs or incomes of the model. If the values represent a lower share of the results, then, its variation would not be impactful enough. The second characteristic is their uncertainty based not only on the way they were estimated but also on the probability of changing in the future.

The chosen parameters for being analysed were the RFH, the transportation cost, the value between the automated and the manual collection, the market selling price, and the facilities costs.

6.3.1 RHF Analysis

There is one pivotal conclusion concerning costs in both scenarios. The RHF that Portugal is planning on implementing is 0.04€ per unit collected independently of the type of collection (3Drivers & NOWA, 2020). If, in fact, this decision goes through, the costs will represent more than two-thirds of the system's costs.

Although has already mentioned during the analysis, there are benchmarked DRS mentioned in Chapter 2 that have different RHF for the two types of collection. Usually, this fee is higher for the automated collection in order to create incentives for Retailers to install RVMs which would reduce the logistical burden of counting bottles upstream.

Therefore, there is a necessity of analysing optimal fee combinations in order to assess scenarios for different RHF and their relation to the total system's cost. Figure 23 presents a visual representation of the different combinations of RHF that are reasonable to consider and its impact on the total cost of the system.

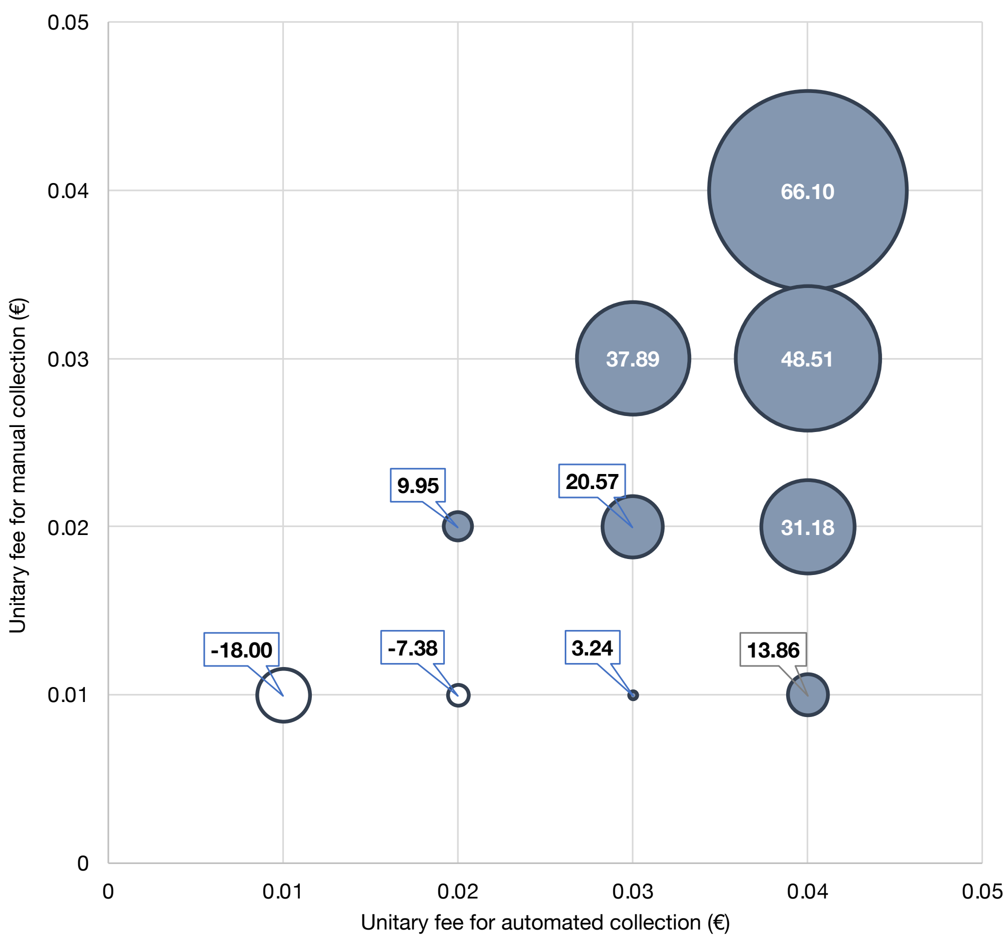

Figure 23 - RHF Possible Combinations and Impact on the Total Cost

In the case that, the Portuguese system's administrator would be reluctant to decrease all the fees to a lower value than 0.04€/bottle, there is always the possibility of reducing only the manual collection RHF. If the manual RHF is reduced to half, the system's cost would be around 31 million. There is even the possibility of having profit (negative values in Figure 23) if the fee paid is 0.01€/bottle to the manual and 0.02€/bottle or less to the automated collection.

In conclusion, the RHF values need to be considered in order for the system to become competitive in cost with other collection systems and to also reduce the overall cost of the system. Minor adjustments in the RHF can serve also to compensate for unexpected potential profit losses or cost increases.

6.3.2 Impacts On The System's Cost

In this section, several parameters will be subjected to a sensibility analysis for the baseline case (scenario 1). As mentioned previously, the parameters were selected either by their high degree of uncertainty or by their significant contribution to the total System Cost.

In Figure 24, the selected parameters of Transportation Cost, Market Selling Price, Facilities Installation Cost and, the percentage of the automated collection will suffer variations as high as 30% in order to assess the possible impact that they might have on the objective function.

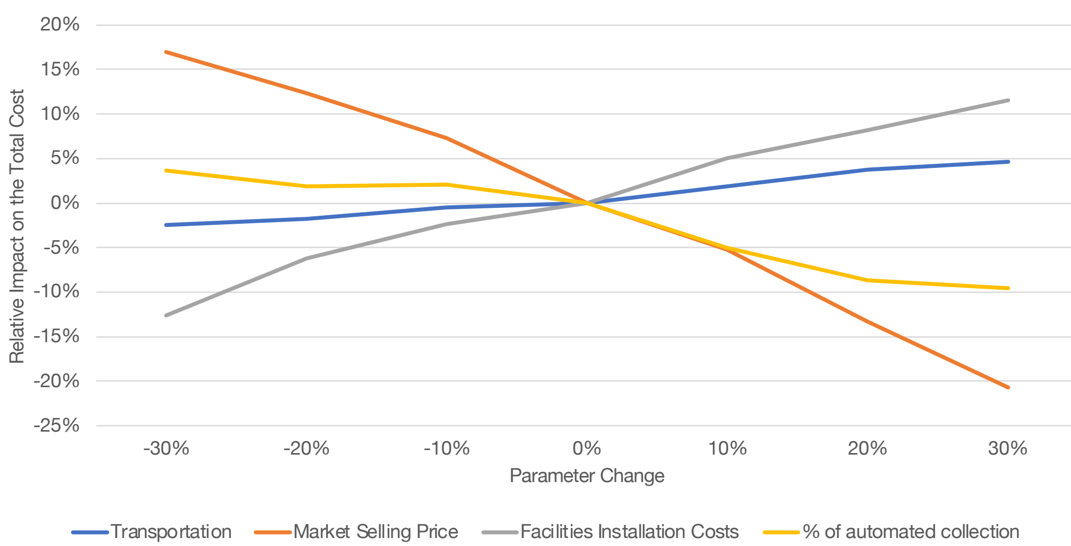

Figure 24 - Sensibility Analysis to Selected Parameters

In a rising inflation period, it is important to be aware that the parameters related to prices and market quotations would easily change in the future to higher values rather than lower ones. Therefore, the Market Selling Price, Transportation and Facilities Installation Costs will be focused on the hypothesis of a rising price scenario.

As it is possible to conclude, it is even beneficial for the Market Selling Price to be higher which means that it will bring the system more income lowering the solution's cost. In addition, among the parameters studied, this is the one that has the most impact on the objective function. An Increase of 30% on the materials selling price would significate a decrease of around 20% in the objective function cost. Concerning the transportation costs, it is also very likely that the cost may suffer a raise. However, the impact on the objective function is lower than, for example, a facility installation price growth.

Concerning the percentage of automated collection, as it was stated before only in qualitative terms, its increase would decrease the logistical burden of counting bottles. However, as is possible to conclude from the observed variation, the cost does not reduce significantly as it was expected. On the opposite side, if the installation of RVMs is less widespread than what is forecasted for the Portuguese DRS, the impact on cost would not be outstanding. This conclusion is extremely relevant because it assures the system's administrator that there is a buffer when it comes to the installation of the automated collection.

In conclusion, this subsection focused on assessing especially the impacts of rising costs in the future. As it was possible to conclude, these impacts would end up being dominated. In the following section, the Chapter's main conclusions will be made.

6.4 Chapter Conclusions

In this Chapter, two main types of analysis were made to the computational results. The first was the scenario analysis and the second was the sensibility analysis. They brought perspective to the analysis of the results for a further critical understanding of the issue and possible solutions.

Two scenarios were built. The baseline one and, the second representing the network without the Counting process. By comparing the network and costs of each, similarities but also some differences were found. In the network, in terms of Warehouse positioning, only minor changes were noticed. As for the flows, these changes mainly originated from the fact that, in the second scenario, Counting Centres did not exist. This means that the flow allocation only took into account the Warehouse and Recyclers' positioning where, in opposition to the first scenario, the model had to balance the flows and positioning with the Counting Centres too. Concerning the processing capacity usage of the facilities, there are Warehouses that use only a small part of their potential. As explained before, this happens mainly due to the constraint that imposed a maximum distance allowed between Municipalities and Warehouses. Hence, some Warehouses have to be installed in regions due to the proximity and not due to a high amount of waste to collect. Another issue to be tackled further is the fact that the Recyclers are receiving an asymmetrical amount of waste which, in reality, might not be possible.

Concerning the costs, the comparison of the two scenarios brought some relevant conclusions that are worth highlighting. The cost structure alters slightly since, in the second scenario, there is no Counting Centre related costs. These costs that disappear, are similar to the total system's cost reduction that is observed between the first and second scenario around 26.10 million. The transportation costs only suffer a small reduction. Since the second scenario did not account for the counting process, the possibility of fraud in the counting process was an issue discussed. The conclusion was that, possibly, it would have a lower impact than the costs of installing Counting Centres.

The main issue concerning the costs is unquestionably the RHF. They represent over two-thirds of the costs in both scenarios. For this reason, the first topic to be approached in the sensibility analysis was precisely due to its impact on cost. A visual representation of a variety of fee combinations was shown and, the conclusion was that costs can be reduced considerably if lower fees are implemented. One of the discussed options was to provide a different RHF to the manual and automated collection as an incentive for putting into practice the latter one (paying a higher RHF). This will mean fewer logistical burdens upstream.

Concerning the sensibility analysis, the focus was to assess rising variances rather than decreasing ones. The main conclusions from it are that the effects and impacts of transportation and facilities installation costs are controllable and, even large increases in their price would not implicate a large variation on the objective function.

In the next Chapter, the main work's conclusions, limitations and future analysis will be presented in order to give closure to this dissertation.

Chapter 7 – Conclusion and Final Remarks

In this concluding Chapter, the summarization of the work will be made. In section 7.1. the main conclusions will be presented. Then, in section 7.2. limitations found will be shown. Finally, section 7.3. will discuss future work to develop.

7.1 Main Conclusions

Throughout this work, several topics were discussed and several takeaways were made. However, all these conclusions were convergent in one main topic – the study of the implementation of a glass beverage packaging DRS scheme in Portugal and its network design and planning.

In the first part, the context was settled. As it is known, Portugal, and other countries in Europe, are far from achieving recycling or reuse targets for packaging materials such as glass. Important is to state that Portugal was not even able to still achieve the recycling target defined for 2011 which was to recycle 60% of the glass (REA | APA, 2021). Therefore, the need to rethink the Portuguese packaging waste management approach is of high relevance. This is where this work is positioned. Several DRS in Europe were benchmarked but one main conclusion arose, there is a need for improving the network design structure of it since the aim is not only to increase the recycling rate but also to be able to turn the DRS into a competitive method for beverage packaging waste management. Therefore, the need for a strategic network design and planning optimization must be studied so that, logistics costs can be reduced.

One of this work's objectives was to perform a literature review of the DRS related topics in order to assess this matter's state-of-the-art. It was concluded that the DRS is a recent, but rising research topic. In other words, the number of articles produced has been growing over the years. Concerning the materials in focus, mainly two categories are present – the beverage packaging waste and the WEEE.

In the DRS literature review, there was one key finding that was comprehensively studied. There is no research concerning strategic network design models applied to DRS schemes. This constitutes a major research gap. Several economic or recycling efficiency types of research were found. However, no application in a reverse logistics design and planning approach was discovered. Once more, this work shows its relevancy in studying a logistics approach to the DRS. For that reason, the literature review proceeded and analysed strategic reverse logistics network design and planning models applied to waste management. Resemblances were found namely in the core decision variables that this works model is intending to have.

In order to build the mathematical formulation, three types of decisions were considered. The facilities positioning, the flows quantities allocation and, the inventory level amounts. After, real data parameters applied to the Portuguese case were calculated and served as input in the model. In addition, sets of potential locations for Warehouses and Counting Centres were built.

Concerning the outcomes and results of the model's applicability to the Portuguese context, several conclusions were taken. Firstly, two scenarios with different schemes were studied. The first considered the existence of Counting Centres and, the second considered a simpler scheme without the existence of Counting Centres.

The total cost of the systems for a time span of 5 years of operation was around 66 million for the baseline scenario and, around 40 million for the scenario without Counting Centres. The Warehouses' positioning was approximately similar in the two scenarios. Minor changes from the first to the second scenario happened but were explained by the fact that there were no flows to Counting Centres in the second scenario. Concerning the Counting Centres positioning in the first scenario, four opened. Two in the Lisbon Metropolitan Area and two in Porto Metropolitan Area. In addition, the configuration is considered to be reasonable in the reality.

In regard to the Warehouse flows, several Warehouses were working close to the maximum capacity. However, there were four Warehouses in both scenarios that were working using less than 20% of the available capacity. In reality, a more in depth evaluation of the economic viability of these locations should be performed. As for the Counting Centres' capacity usage in the first scenario, three of those facilities work close to their maximum capacity. The other, in the Porto Metropolitan Area, opens in the period when the Gondomar facility starts to work at 100% capacity. This new opening happens to cover the growth in the number of bottles processed close to the Porto Metropolitan Area.

Recycling facilities' inbound flows lead to some remarks. This location set was already defined because it represents real glass Recycling facilities in Portugal. In the flows supplying the Recyclers in the results, one of the facilities, the *Figueira da Foz* one, does not receive any quantity. The Recycling facilities that receive more quantities are the *Amadora* and *Vila Nova de Gaia* because they are close to the Metropolitan Areas that produce more waste.

Regarding costs, there is one that stands out in both scenarios which is the RHF. This cost represents more than two-thirds of the system costs. A sensibility study was made to look for solutions to mitigate this issue. The reduction of the RHF only for the manual collection as it is common in other countries' systems, can reduce effectively the costs of the system. This cost will determine if the DRS can be in fact a competitive waste management solution for beverage packaging or not.

Other costs were also submitted to a sensibility analysis. The market selling price of recovered materials is the one that impacts more the total system's cost. One interesting fact concluded was that, if the share of the automated collection is reduced by 30%, which means that more bottles have to be counted, the impact on the system's cost suffers an increase of less than 5%.

This work had the purpose of fulfilling a gap in the DRS research and, also, performing the strategic network design and planning of a future network for Portugal. With these conclusions, several decisions can be confidently taken when implementing the future system.

However, there are some work limitations that need to be accounted for. They will be described in the next section.

7.2 Main Limitations

One key limitation found, and already discussed in Chapter 2, is the non-consensual opinion concerning the inclusion of glass packaging in the system. There are several arguments against the implementation. For example, the fact that glass has the lower selling price of the different packaging materials, or that, the inclusion of glass in the general packaging DRS would be translated into the need to increase the capacity of the system considerably due to the high volume of glass. In Portugal, the inclusion of glass is going to move forward, although the decision to include this material can be revoked back until 2027 (3Drivers & NOWA, 2020).

Another considerable limitation is regarding the implementation of the DRS in general. The mission of the system has an opposing incentive to one of the system's funding (the uncollected deposits). Notwithstanding, glass recycling targets in Portugal are not met yet. One way of funding the system without being with uncollected deposits or market sale of material is to charge a fee to beverage producers for every unit placed in the market. This fee is not clear yet that will be part of the Portuguese system hence, it was not considered.

Regarding the modelling and the Portuguese network characterization, although there is some information on the future system already provided by (3Drivers & NOWA, 2020), there is still no concrete information in regard to the real characterization. However, it is believed that the network modelled in this work will resemble the main aspects of the Portuguese network's future configuration. Also, since there is no budgeting on the future DRS nor information about the cost of SIGRE, it was not possible to compare the costs of the DRS network and analyse if it is a feasible or even competitive packaging waste solution.

Other aspects such as data parameters could be more precise if there was more information available only concerning this topic, for example, the number of HORECA and Retail establishments and their sales of glass beverage packaging. Besides this, sensitivity analyses were made already to estimate possible deviations from the real values. Although difficult to estimate in the next five years, the inflation rate could have been implemented in the model.

Finally, concerning the computational limitations, there were some difficulties observed. Initially, the model would also perform freight planning decisions. However, due to computational limitations, this module was not able to be implemented and processed in a feasible time.

Nevertheless, these limitations can be solved by future work's development of the topic. The next section will discuss some key suggestions.

7.3 Future Work Development

The purpose of this section is simply to open the discussion for new research or enlargement.

Concerning the more qualitative analysis of the DRS, there are some missing remarks. This work aimed at studying the DRS which is known will possibly be implemented in Portugal. However, there is also a need for a cost-efficiency study of different waste management approaches for beverage packaging applied to Portugal. The SIGRE and the DRS are not the only solutions to the packaging waste management issue. A transversal study comparing relevant systems would be useful.

In the DRS network model formulation, some characteristics, in future research should be taken into account. The most important is a restriction that balances the waste distribution among Recyclers. Or even, assigning a processing capacity to each recycler. Also, it would be interesting to study the relationship between the availability of collection points and the return rate.

Another critical development should be to find cost-effective alternatives for counting clearance. The existence of Counting Centres just for that purpose carries high costs and adds a large logistical burden to the network. Resemblances can be possibly benchmarked in other industries where goods have to be also counted.

Since the Portuguese system is going to implement the DRS not only for glass but also for plastic bottles and aluminium cans, it should be interesting to expand the work to find an interconnected solution for the Portuguese DRS in general. For example, this network would include different products which had to be carried to different recycling sites among other requirements.

Furthermore, this study focused on strategic-tactical level decisions. There is still missing research at operational levels. For example, the study of the routing for the beverage waste collection.

In conclusion, this work already fulfilled a critical research gap. Hopefully, it will open the discussion about the DRS schemes, help research development further, and help Portuguese decision-makers to take more confident logistics decisions.

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Annexe - Potential Locations List

Municipality	NUT	(Potential) Entity
Albufeira	Algarve	Warehouse
Santa Maria da Feira	Área Metropolitana do Porto	Warehouse
Guimarães	Ave	Warehouse
Cantanhede	Região de Coimbra	Warehouse
Batalha	Região de Leiria	Warehouse
Arraiolos	Alentejo Central	Warehouse
Odemira	Alentejo Litoral	Warehouse
Fronteira	Alto Alentejo	Warehouse
Ponte da Barca	Alto Minho	Warehouse
Vila Pouca de Aguiar	Alto Tâmega	Warehouse
Alcochete	Área Metropolitana de Lisboa	Warehouse
Arouca	Área Metropolitana do Porto	Warehouse
Cabeceiras de Basto	Ave	Warehouse
Proença-a-Nova	Beira Baixa	Warehouse
Belmonte	Beiras e Serra da Estrela	Warehouse
Terras de Bouro	Cávado	Warehouse
Moimenta da Beira	Douro	Warehouse
Alpiarça	Lezíria do Tejo	Warehouse
Constância	Médio Tejo	Warehouse
Cadaval	Oeste	Warehouse
Anadia	Região de Aveiro	Warehouse
Arganil	Região de Coimbra	Warehouse
Figueiró dos Vinhos	Região de Leiria	Warehouse
Baião	Tâmega e Sousa	Warehouse
Alfândega da Fé	Terras de Trás-os-Montes	Warehouse
Nelas	Viseu Dão Lafões	Warehouse
Vila Franca de Xira	Área Metropolitana de Lisboa	Warehouse
Almada	Área Metropolitana de Lisboa	Warehouse
Paredes	Área Metropolitana do Porto	Warehouse
Vila do Conde	Área Metropolitana do Porto	Warehouse
São Brás de Alportel	Algarve	Warehouse
Mafra	Área Metropolitana de Lisboa	Warehouse
Alcácer do Sal	Alentejo Litoral	Warehouse
Vidigueira	Baixo Alentejo	Warehouse

Municipality	NUT	(Potential) Entity
Barreiro	Área Metropolitana de Lisboa	Counting Centre
Loures	Área Metropolitana de Lisboa	Counting Centre
Faro	Algarve	Counting Centre
Amares	Cávado	Counting Centre
Bombarral	Oeste	Counting Centre
Condeixa-a-Nova	Região de Coimbra	Counting Centre
Abrantes	Médio Tejo	Counting Centre
Alvaiázere	Região de Leiria	Counting Centre
Gondomar	Área Metropolitana do Porto	Counting Centre
Aljustrel	Baixo Alentejo	Counting Centre
Vagos	Região de Aveiro	Counting Centre
Alcobaça	Oeste	Counting Centre
Oliveira de Azeméis	Área Metropolitana do Porto	Counting Centre
Vila Nova de Gaia	Área Metropolitana do Porto	Recicling
Amadora	Área Metropolitana de Lisboa	Recicling
Figueira da Foz	Região de Coimbra	Recicling
Marinha Grande	Região de Leiria	Recicling

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