By-products valorisation – exportation of meat by-products to China

Diogo Correia Monteiro Cabral Campello

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Industrial Engineering and Management

Supervisor: Prof. Susana Isabel Carvalho Relvas

Examination Committee

Chairperson: Prof. Ana Isabel Cerqueira de Sousa Gouveia Carvalho

Supervisor: Prof. Susana Isabel Carvalho Relvas

Members of the Committee: Prof. Sara Sofia Baltazar Martins

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Declaration

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

Declaração

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

Abstract

Firstly, the Case study is presented, as it aims to contextualize by presenting the MobFood Project, more specifically, the PPS-7 and all the constituent entities. Then, the literature review aims to provide a background regarding the most used methods for meat by-products recovery, as well as some notions related with collaboration. Additionally, concepts related to VRP and waste collection problems are presented in order to display some knowledge that is used as a theoretical background to the collection process developed in this dissertation.

The aim of this dissertation is to highlight the need for reducing the waste of pork by-products and to propose a solution that adds value to them. More specifically, the proposed solution is to collect by-products from slaughterhouses located in multiple Portuguese regions and export them to China, a country where these are highly valued. The methodology is divided into two phases: the first phase, which refers to how by-products are collected and treated in national territory; and the second phase, referring to the international transport of such by-products. All costs incurred are demonstrated and balanced with the expected revenues, to comprehend if the process of export is lucrative.

For the second phase, two means of transportation were studied: the ocean and air transport. After balancing all the costs involved for both means of transport with the revenues, it was concluded that air transport is not a viable option, whereas the ocean transport might be under some scenarios that are discussed throughout this work.

Keywords: By-products recovery; Sustainable collaboration; VRP; Waste Collection problem; Air freight costs; Ocean freight costs.

Resumo

Em primeiro lugar, é apresentado o Estudo de Caso, já que este pretende contextualizar através da apresentação do Projeto MobFood, mais especificamente, o PPS-7 e todas as entidades constituintes. Em seguida, a revisão da literatura visa fornecer uma base teórica em relação aos métodos mais utilizados para recuperação de subprodutos de carne, bem como algumas noções relacionadas com a colaboração. Adicionalmente, são apresentados conceitos relacionados com VRP e problemas de recolha de lixo, de modo a evidenciar alguns conhecimentos que servem de base teórica ao processo de recolha desenvolvido nesta dissertação.

O objetivo desta dissertação é evidenciar a necessidade de redução do desperdício de subprodutos suínos e propor uma solução que valorize os mesmos. Mais concretamente, a solução proposta consiste em recolher subprodutos de matadouros localizados em várias regiões portuguesas e exportá-los para a China, um país onde são muito valorizados. A metodologia está dividida em duas fases: a primeira fase, que se refere à forma como os subprodutos são recolhidos e tratados em território nacional; e a segunda fase, referente ao transporte internacional de tais subprodutos. Todos os custos incorridos são demonstrados e balançados com as receitas esperadas, para verificar se o processo de exportação é lucrativo.

Para a segunda fase, foram estudados dois meios de transporte: o marítimo e o aéreo. Após balançar todos os custos envolvidos para ambos os meios de transporte com as receitas, concluiu-se que o transporte aéreo não é uma opção viável, enquanto o marítimo pode sê-lo sob alguns cenários que são discutidos ao longo deste trabalho.

Palavras-chave: Recuperação de subprodutos; Colaboração sustentável; VRP; Problema de recolha de lixo; Custos de carga aérea; Custos de carga marítima.

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Acronyms

ACE- inhibitory – Angiotensin converting enzyme

AQSIQ – Administration of Quality Supervision and Inspection Quarantine

BAF – Bunker Adjustment Factor

BIP – Border Inspector Post

BSE – Bovine Spongiform Encephalopathy

CAF – Currency Adjusment Factor

CO_2 – Carbon dioxide

CPC – Centro de Processamento de Carnes

CYRC – Container Yard Receiving Charge

DAT – Delivered at Terminal

DDC – Destination Delivery Surcharge

D/O – Delivery Order

DTHC – Destination Terminal Handling Charge

EBS – Emergency Bunker Surcharge

EC – European Commission

ERS – Equipment Repositioning Surcharge

EU – European Union

FAO – Food and Agriculture Organization

FCL – Full Container Load

FEDER – Fundo Europeu de Desenvolvimento Regional

FIPA – Federação das Indústrias Portuguesas Agroalimentares

FLW – Food Loss and Waste

FSC – Food Supply Chain

FTL – Full Truck Load

FUSIONS - Food Use for Social Innovation by Optimizing Waste Prevention Strategies

GHG – Greenhouse gas

GMO – Genetically Modified Organism

GRI – General Rate Increase

HAWB – House Airway bill

ISPS – International Security Port Surcharge

ITS – Indústria de Transformação de Subprodutos

Kg – Kilograms

LCL – Less than a Container Load

LTL – Less than a Truck Load

MAWB – Master Airway bill

MPC – Meat processing centre

PBS – Pick by Stock

PPS-7 – Process, Product or Service, seventh package

R&D – Research and Development

SDG – Sustainable Development Goal

THC – Terminal Handling Charge

TSE – Transmissible Spongiform Encephalopathies

UN – United Nations

UNEP – United Nations Environment Programme

USA – United States of America

VRP – Vehicle Routing Problem

1. Introduction

1.1 Problem background and motivation

Food is and will always be a central need for all human beings. Population growth and the consequent demand growing for food and drinks are occurring at speeds never observed. Therefore, global trends are shaping the demands that modern agriculture and food production must meet, meaning that a rising global population requires access to safe and reliable sources of nutrition. However, a rise in food production is not enough, considering the limited resources we have on earth. With that in mind, we must act in a sustainable way.

Although many societies are currently suffering from chronic hunger, it is estimated that one third of all food produced is being lost or wasted throughout the entire FSC (food supply chain). This is a clear sign of unsustainability, since the problem is not the lack of food quantities to feed all societies, but instead, the way food is managed and distributed. This problem calls for innovative ways to, not only prevent FLW (food loss and waste), but also to recover FLW and food parts that are usually not consumed and add value to them. This requires the use of new technologies as well as different business models and value chains.

This is the starting point and the main motivation for the ***MobFood*** **Project** - *Mobilization of scientific and technological knowledge in response to challenges,* more specifically, for the working package **PPS-7** - *Logistics - Sustainable Collaborative Agri-Food Logistics Chain*. Two main acting pillars can be highlighted: the characterization of logistic activities regarding the agri-food sector so that motivations, constrains and requirements related to sustainability can be identified and; the research and development of process management methodologies applied to logistic activities which make it possible to base and justify decisions in an integrated way, while fostering collaboration between FSC stakeholders.

When studying all companies belonging to the PPS-7, each of these entities are constantly under pressure to provide high quality and diverse products at the right place and at the right time through their developed omni-channel. This pressure caused by the constant high demand for food products may lead to over production, which leads to FLW. With that in mind, all companies that will be studied in this dissertation have the interest of being included in the *MobFood Project,* where every company is able to collaborate with other entities and, therefore, enter in a win-win situation.

The present master dissertation is being developed within IST (*Instituto Superior Técnico*), which is another entity working within PPS-7. The main objectives of the present work will be explained in section 1.2.

1.2 Objectives

A food supply chain involves a wide variety of products that require the action and interaction of multiple entities. For this reason, sometimes there can be unnecessary waste, originated due to lack of communication and collaboration between the stakeholders involved. Therefore, the first major step is to map the entire supply chain and identify the main sources of waste and breaks, so that the entities can act as a group and correct mistakes in a sustainable way. Collaborative logistics play a big role in this step.

In the case of meat, ETSA, Greenyard Logistics and Sonae MC are the co-promoters within PPS-7 that operate in this sector. In order to propose collaborative and more sustainable operations, a first step is to reach a consensus on system definition and data collection. Aspects like the specific product that is being treated; the weight measure being used; the measure periodicity and the type of information being shared; and the locations being used by all entities have to be defined, as well as definitions of loss, waste and by-product. Also, processes concerning the meat value chain (primary production, manufacturing, retail and waste/ by-products treatment) need to be entirely understood by all the entities involved. Then, in a second step, opportunities to value the by-products, residue and waste in the meat value chain need to be mapped in the collaborative supply chain. Finally, all stakeholders need to identify opportunities to innovate and/or improve all logistics in order to stimulate a circular economy in the meat value chain.

Within the work plan of PPS-7, the objective of the master's dissertation is to build a decision support framework based on the meat supply chain that shows a possible attractive valuation opportunity for meat by-products.

More specifically, the present dissertation will be to explore the possibility of exporting pork by-products to China, a country where such by-products will surely be properly valued, thus not being wasted (the main features of the Chinese pork by-products' market which make such products so valuable will be deeply explained in section 4.2.1.1). This process can be divided into two operations: the collection and storage of the pig meat by-products; and then the transport of such products to China. This idea will be presented through the explanation of each step that must be put into practice, as well as all costs involved, in order to implement the collection, storage and transport processes.

1.3 Document structure

The present Dissertation is divided into the following well-established chapters: Introduction, Case study, Literature review, Methodology, Implementation and results and Conclusions, limitations and future work suggestions.

The **Introduction** is the present chapter. The chapter aims to contextualize the reader by presenting the background and motivation for the present dissertation, the problem statement and objectives of this work. In addition, the structure of the document is also herein presented.

The second chapter, **Case study**, aims to present the national meat sector and the entire *MobFood* project, more specifically, PPS-7, which is the package related to the logistics. The chapter starts with the description of the national meat sector, since the focus of the dissertation is to explore innovative ways of recovering and adding value to meat by-products and waste. Moreover, the *MobFood* Project, as well as all the promoters involved in PPS-7 that act along the meat sector, by explaining how each entity contributes to the project. Sonae MC and Abapor are described in greater detail. Sonae MC, one of the most recognized food retailers in Portugal, is studied in greater detail in order to better comprehend how a general Portuguese meat supply chain works. With that in mind, Sohi's Meat Processing Centre and Sonae MC stores' processes are thoroughly studied. Abapor is also paid more attention to, due to its core business: the collection, transport, sorting and unpacking of animal-based by-products, which is aligned with what is intended to be implemented in the present work.

The third chapter, **Literature review**, aims to provide some theoretical background to support future work developments. The following themes will be studied in this chapter:

- **Section 3.1 - Agri-food industry**: the characterization of the industry, the importance of implementing a sustainable development into the industry and the most relevant existing legislation within the food industry will be main topics of this section.
- **Section 3.2 - Food waste**: the food loss and waste contextualization, the absence of a commonly agreed definition for food waste, the main causes, preventive and corrective measure for food waste will be discussed in this section. Also, the recovering and value-adding regarding meat by-products will be studied in greater detail.
- **Section 3.3 – Collaboration**: the definition, the main benefits and risks of implementing collaboration among stakeholders within a food supply chain will be discussed in this section. Additionally, the steps for implementing sustainable collaboration in a supply chain will be studied. Finally, some examples of past initiatives to reduce and add value to food waste that occurred in the recent years in Europe will be mentioned.
- **Section 3.4 – VRP for waste collection**: concepts related to general optimization models are demonstrated in this section. Vehicle Routing Problems are also introduced in this section so that the reader can better comprehend the importance of minimizing the total costs when designing collection routes. At the end of this section, the main concepts related to the smart collection of waste are outlined, as well as the mathematical formulation that is often used when solving waste collection problems through an optimization model.

Then, in the fourth chapter, **Methodology**, the idea proposed by the author in order to add value to pig meat by-products is thoroughly explained. This idea consists on the collection, storage and export of pig meat by-products. This proposed methodology is divided into two main phases: the collection and storage phase, which refers to how the by-products are collected and treated in national territory; and the export phase, referring to the transport and arrival of such by-products in China. The main goal of the first phase is to find the best set of trajectory-trucks which find the minimum collection cost. The main objective of the second phase is to study and compare the main ways of transport when it comes to exporting meat by-products to China, while studying all costs inherent to the entire export process. The main physical and contractual conditions for meat by-products exports to China are studied as well. Finally, the choice of incoterm, as well as its justification, are established in a clear way.

In the fifth chapter, **Implementation and results**, it is explained how the methodology proposed in the previous chapter was implemented by the author. This chapter's structure is very similar to the methodology's, as it is also divided into the same to phases. Regarding the first phase, all the costs related to collecting, storing and moving the goods to the port or airport of departure are explained and demonstrated. Then, just like in the previous chapter, the costs related to the export of the collected goods from Lisbon (Portugal) to Qingdao (China) are calculated and demonstrated as well. Many scenarios related to the quantity being collected, as well as to the warehousing costs, ocean/sea freight costs and air freight costs were created in order to study different possible alternatives. Then, a cost/benefit analysis is implemented, where all the costs that were previously calculated for the different created scenarios are summed and then compared to the expected revenues generated from the sale of the goods being exported. The chapter ends with a sensitive analysis regarding the relationship between the costs spent by the exporter and the frequency of collection of pig meat by-products from the slaughterhouses under study.

This work ends with a chapter called **Conclusions, limitations and future work suggestions**. In this chapter, as the name implies, all conclusions taken from the implementation of the work developed throughout this dissertation are stated, as well as the main limitations of the work put into practice. The chapter ends with some future work suggestions, thus explaining how the work herein developed can be carried on in the future.

2. Case study

This chapter aims to contextualize the reader, explaining the problem being studied and how important is the chosen theme. Firstly, the national meat sector will be characterized in order to contextualize the reader by exhibiting the main constrains and opportunities of this sector. Then, the *MobFood* project will be explained, more specifically the PPS-7, which is dedicated to the logistics topic of the within overall project. Additionally, all the co-promoters within PPS-7 that act in the meat sector will be mentioned and described. Sonae and ETSA will be described in greater detail, in order to better comprehend the entire meat supply chain, especially when it comes to meat's processing, distribution and potential recovery. The study of Sonae, Stec Raporal and ETSA will allow the reader to better understand the main processes applied in each stage of the meat supply chain, as well as the large dimension of meat waste that occurs in each stage. The information herein presented results from documents, meetings and workshops held under the scope of the *MobFood* Project and visits to Sonae's Meat Processing Center (CPC).

2.1 National meat sector characterization

In order to propose a solution to solve the issues related to valuing by-products and reducing waste, it is crucial to understand the sector that is being studied, which is the national meat sector.

Animal production occupies a prominent place in the agricultural sector. According to the latest Eurostat 2017 data, the European Union, with its 28 Member States, has about 11 million agricultural/livestock exploitations, which employ 22 million citizens. The entire food sector involves 44 million workstations. Meat and other animal products in the European Union accounted for 176 billion euros in 2017, which means 41% of the total agricultural and livestock production [20].

In Portugal, the livestock represents near 37% of all agricultural production. In a general view, animal production has been growing. However, it is highly dependent on intermediate consumption of goods like cereals, food for animals and energy, which are mostly imported. The main livestock sectors are, in terms of business volume, the production of milk, poultry and pig meat, followed by beef, sheep and goat meat [21].

In the meat sector, 80% of the pig meat is under an open market, which means that any company can enter or leave the market without having to pay any taxes to the state. This type of meat is highly exported by Portugal, being Spain, Angola, United Kingdom, France and now China the main exportation markets. In the next years, Portugal expects to export near 1000 tons of meat (which is 15% of the national production) to China, thus factoring 100 million euros. Venezuela was also a big exportation market until 2015, but recently it stopped being due to its crisis [23].

The entities operating within this sector, whose flow of products and information through collaboration constitute the meat supply chain, are presented in Figure 1. The main picture basically shows us how cattle becomes meat products for citizens, as well as all the stages which meat must go through.

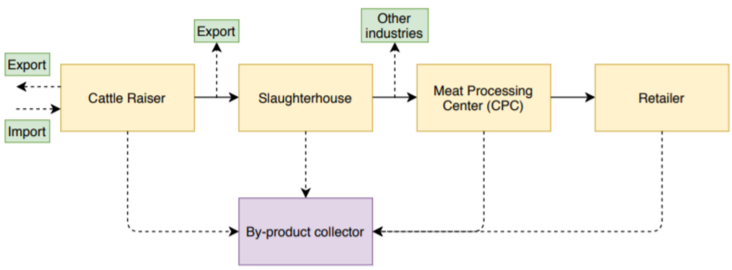


Figure 1 - Meat Supply Chain

The sector is highly concentrated and fragmented. This means that explorations belong to few entities but each exploration, due to its location, is managed differently. This is a big obstacle for collaboration between entities in the meat sector. The sector under study also requires long trust relationships between the entities involved. This can be a hard goal to accomplish, since all the entities involved are spread across the country and they are sometimes far away from each other [22].

The meat sector is highly regulated. It is very important that all meat must be properly regulated in order to guarantee the quality of the meat. Any flaw in this step can harm the consumers and jeopardize their health. This topic will be more deeply explored in section 3.1.3.

2.2 The MobFood project

The *MobFood* Project is the result of a joint mobilization project entailed by many agri-food sector actors who seek to respond to challenges related the promotion of a more competitive food industry. The main goal is to promote new strategies based on technological and R&D development in order to obtain innovative products, services and processes. Such goal is accomplished by acting along the whole value chain and promoting the collaboration between the business sector and non-business entities. The main principles to be followed by the project are food safety and sustainability, the food for health and well-being and the safe food and quality. The food sector is intended to be sustainable, fully integrated, transparent, resource-efficient and centered on the consumer [1]. The *MobFood* consortium is composed by 47 entities that include companies who act on different agri-food subsectors and non-business companies that complement the research as a whole by providing specific knowledge that other companies do not have [9].

The project started in the first of December of 2017 and the end is scheduled for the thirty first of May of 2021. It is financed by *Lisboa 2020*, *Compete 2020*, *Portugal 2020* and FEDER (*Fundo Europeu de Desenvolvimento Regional*) [2]. The project is composed by 9 work packages, numbered after the acronym PPS (standing for Product, process or Service): 1) Emerging Technologies (which has not received funding after the project proposal evaluation and is not being developed), 2) Resources Valorization, 3) Sustainable Packaging, 4) Nutrition, Health and Well-being, 5) Quality and Food Safety, 6) Authenticity and Traceability of products, 7) Logistics, 8) Consumer and 9) Coordination, implementation, dissemination and exploitation of results [3]. The present work is being developed within PPS-7 (Logistics), which aims to explore all benefits resulting from the collaboration between companies within the agri-food supply chain, thus implementing a sustainable development.

2.3 PPS-7 (Logistics - Collaborative Sustainable Agri-Food Logistics Chain)

The main objective of this PPS is to investigate and develop innovative logistics processes and management methodologies [4]. Different restrictions, conditions, requirements and any collaborative opportunities that have been identified for the agri-food sector are listed and explored here. Some key-drivers were already identified by the co-promoters: globalization; intensity of competition; retail promotional trends and created bottlenecks; the increase of environmental pressures and the subsequent changes of consumer's profile, which is translated in the organic market's growth; awareness of social and environmental impacts in the supply chain, not only valuing and quantifying the economic impact; the aging of the population and the need to find new nutritious and healthy solutions for the eldest age group, as well as adapting some distribution networks to satisfy those needs; the efficient integration of supply chain partners, thus gaining competitive advantage; promoting collaborations between partners, thus ensuring long-term sustainability for the supply chain; technological advance and the need to automatize the entire sector and to hire specialized workers; the need to promote the share of information between entities, thus increasing efficiency of operations and promoting trust and synergies between entities within the supply chain.

Two different case studies are being studied within PPS-7: fruits & vegetables and meat [5]. However, the present work will focus on the meat sector. Sonae, Greenyard Logistics, ETSA Group are the main PPS-7 co-promoters acting in the meat sector [4]. These companies are presented in the following sections

2.3.1 ETSA Group

All ETSA Group companies focus their activities on environmental issues by offering global, safe and sustainable answers. Through their services, they look for the best solutions to value all by-products and all products that contain animal substances. In order to reach this goal, the companies guarantee specialized and integrated answers by using collection devices and respecting all regulations. Nowadays, ETSA is owned by Semapa, one of the main Portuguese industrial groups with presence in the areas of paper and pulp, cement and environment [6].

The ETSA Group was born in 1997, when Sebol – *Comércio e Indústria de Sebo, SA* and ITS – *Indústria Transformadora de Subprodutos Animais, SA*, who were until then competitors in the animal by-products transformation market, decided to join commercial activities. In 2008, the group was integrated in Semapa, representing the environmental pillar of that industrial group [7].

Nowadays, Semapa detains three industrial companies: Navigator, engaged in the manufacture and marketing of paper in Portugal; Secil Group, a cement productor; and ETSA Group, an environment-oriented company that seeks the high value of animal products and by-products. The structure of Semapa Group can be seen in Figure 2 [6,8].

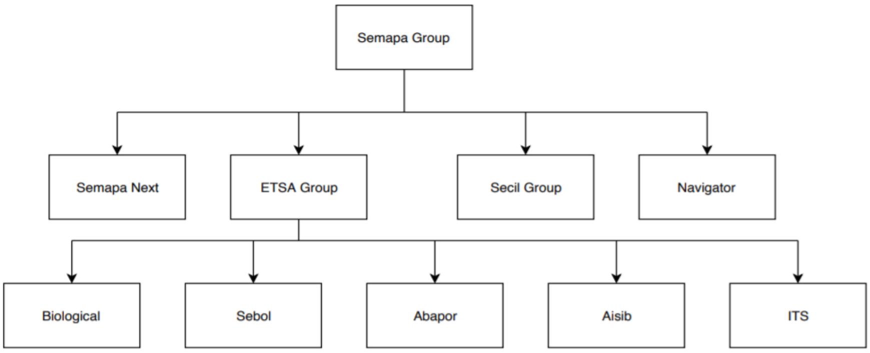


Figure 2 - Semapa Group composition. Adapted to [8]

In the context of the present dissertation, Abapor is the ETSA Group's most relevant component, since this is the company that is accountable for the collection, transport, sorting and unpacking of edible meat by-products. All the information related to ETSA's operational activities provided in this dissertation is based on the work developed by Marta Lopes in 2018, in collaboration with Abapor. This entity, which belongs to the ETSA group, is dedicated to the collection, transport, sorting and unpacking of animal-based by-products [106].

Abapor collects meat by-products throughout the modern distribution, municipal markets, industries and so on, always recording all products' traceability. In the case of the present work, only the collection of meat by-products from slaughterhouses will be considered. Moreover, Abapor performs another business activity that is the supply, installation and maintenance of refrigeration equipment, such as refrigerating chests, plastic barrels or boxes. When transporting by-products, Abapor must follow a set of rules in order to neutralize or reduce risks associated with animal by-products. Such risks, if not mitigated, can put people's and even animals' lives in danger.

Generally, when a product is not sold, it has three possible destinations: donation, when the product is in the end-of-life but is still consumable; waste (trash); or going to recycling entities. When the product is recycled (in this case, by Abapor, the recycling entity), the first thing to be done is to package the received by-products in plastic bags. Then, those bags are put in refrigerated chests, provided by Abapor. Each chest must be identified with the name of the product, with the associated risk category and the collection entity's name (in this case, Abapor). While Abapor is responsible for provisioning the chests and providing proper maintenance, the other entities are responsible for cleaning and preserving such equipment provided by Abapor. When all these conditions are met, Abapor starts the collection and transportation processes. The cold storage time of each by-product performed by each entity depends of the frequency of collection performed by Abapor, which is approximately every three working days. The frequency of collection performed by Abapor is an indicator that must be properly tracked, since, the fuller the chests, the worse the packaging and the worse the conditions under which the by-product is. Such conditions may even reduce the by-product's selling price.

Abapor operates under four collection points throughout mainland Portugal, located in *Vila Nova de Gaia*, Loures, Coruche and Tunes (see Figure 3). All four infrastructures operate in different ways and complement each other in terms of activities performed by each point and their respective flows in order to maximize the efficiency of the entire process and to minimize the total cost.

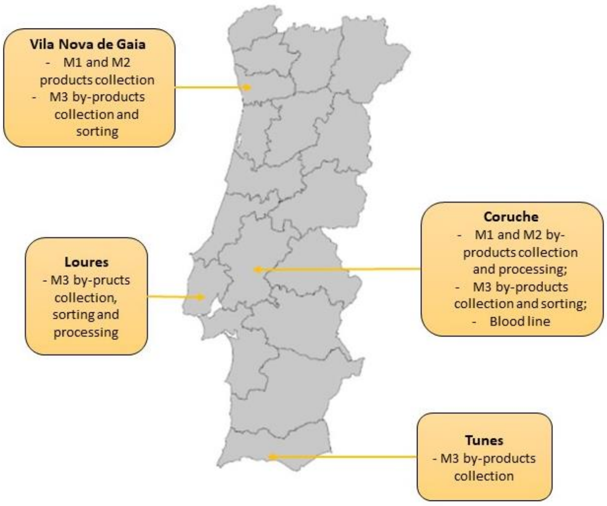


Figure 3 - Abapor's four collection points

Abapor plays an important role in this dissertation, since that is the entity that will be used as reference for the collection process (which was already mentioned in the Objectives and will be deeply studied in the Methodology)

2.3.2 Greenyard

Greenyard Logistics, which has been in Portugal since 2001, operates in the market of providing logistics services and transportation of food products, being more focused on perishable food products, and in the importation and marketing of Fruits and Vegetables. Greenyard Logistics Portugal is located in the center of Portugal and it has a 17.000 m^2 platform which satisfies all the needs that requires temperatures between -25ºC and 18ºC and is constantly supported by cross-docking hubs.

The company was founded in 1987 in Belgium, by Heinz Deprez. Recently, in 2015, there was a merger between Greenyard, Univeg, Noliko, Petralcom and Grenyard, forming the Greenyard Group. Greenyard acts on three main segments of fruits and vegeTables: fresh, frozen and prepared food, being highly well succeeded in all of the three segments [10].

Greenyard also plays an important role in this dissertation, as this is the entity that will provide all the warehousing related costs, which will be deeply studied in the Implementation and results' chapter (see section 5.2.2)

2.3.3 Sonae

We are a multinational group with solid roots and an ambition for permanent progress. Our culture, our way of being and being in business is the bond that holds us together and makes us special in any business or geography. The values we share, which are at our root and in our DNA, are a legacy for the future and for how we create long term economic value. We see each day as a new beginning for new opportunities, new challenges and new triumphs. – Sonae [11]

Sonae was founded in the 18th of August of 1959 as a laminate company; hence the name of the company is *Sociedade Nacional de Estratificados*. Since Sonae's foundation, the company expanded its core business area and suffered numerous changes in its business strategy. It started in the 80's when the company started betting on diversification, by founding new companies in the construction, catering and hotel management industries. In the 90's, Sonae put effort on developing new businesses in the specialized retail industry through brands like Modalfa, Maxmat, Max office, Sport Zone, Worten and others [12].

Nowadays, Sonae is a multinational that manages a diversified portfolio of businesses in retail, financial services, technology, shopping centers and telecommunications, operating in 74 countries, distributed through 5 continents (including operations, third party services, representative offices, franchising agreements and partnerships and excluding wholesale in retail) (2019) with sales volume of 5.951 M € in 2018 [13]. There are multiple business areas owned by Sonae that cover all the businesses described above:

- **Sonae MC** is the leader of the national market in the food retail business that has a group of different formats offering a wide range of products: *Continente* (hypermarkets), *Continente Modelo* and *Continente Bom dia* (convenience stores), Meu Super (franchising stores), *Bom Bocado, Bagga* (coffee shops and restaurants), Go Natural (supermarkets and healthy restaurants), Make Notes, Note! (bookstores, stationary stores), ZU (products and services for dogs and cats), Well's (health, wellbeing and optics) and Dr. Wells (dental medical clinics and aesthetic medicine). It also includes retail asset management.
- **Sonae Fashion** is the responsible for the clothing retail, through brands like Deeply (sports clothes and equipment), MO (clothing, shoes and accessories), Zippy (clothing, shoes and baby and child accessories) and Salsa (jeans, clothing and accessories).
- **Worten** is responsible for Sonae's electronics retail business through Worten (home appliances, consumer electronics and entertainment) and Worten Mobile (mobile telecommunications) brands.
- **ISRG (Sports Retail Group)** was created recently in 2018 when JD, Sprinter, Size? and Sonae joined forces to create this sports retail company.
- **Sonae FS** is the business unit that coordinates financial services. This segment includes *Cartão Universo, Cartão Dá, Continente Money Transfer*, store credit services and MDS, an insurance brokerage.
- **Sonae IM** has an active portfolio management strategy, which aims to create and manage a set of technology companies, linked to retail, telecommunications and cybersecurity. Its portfolio currently includes Bizdirect, S21sec, Inovretail, Bright Pixel and Excellium.
- **Sonae Sierra** is an international company dedicated to serving the needs of real estate retail investors. The company owns 44 shopping centers with a Gross LetTable Area of 2.3 million square meters in 11 countries. It is responsible for the management and marketing of 64 shopping centers.
- **NOS**, which is owned by Sonaecom, which has a jointly controlled influence in the company, with a 25% stake through Zopt, is a telecommunications and entertainment group offering a wide range of telecommunications services to all market segments: residential, personal, corporate and wholesale, having a prominent position in subscription TV services, unlimited telephone and cinema exhibition and distribution in Portugal [14].

Sonae always aims for a sustainable development while imposing their principles on a daily basis: trust and integrity, ambition, innovation, corporate responsibility, cooperation and independency [11]. Sonae has been awarded in the areas of sustainability, efficiency and innovation in the last years.

More specifically, Sonae MC has various brands, as it can be observed in Table 1, which shows how much the company has been investing in diversity in the last years, in order to satisfy the needs of its consumers.

Regarding the near future, the company anticipates an intensely competitive environment. In this scenario, Sonae MC remains committed to pursuing its strategy assertively, which implies an investment in its operations to strengthen its different formats and concepts. The company must maintain high levels of efficiency in innovative solutions, and an expansion of its presence in current and new markets, seeking to achieve its main goal of continuing to deliver a profitable growth and leading [16].

Table 1 - Sonae MC's insignias in the end of 2018. Adapted from [16]

	End of 2018
Total Sonae MC stores	**1108**
Total Owned stores	**758**
Continente	41
Continente Modelo	126
Continente Bom Dia	107
Well's	213
Arenal	0
Bagga	132
Note!	53
Zu	15
Go Natural supermarkets	10
Go Natural restaurants	28
Maxmat	31
Dr Wells	0
Other	2
Total Franchised	**350**
Continente Modelo	9
Meu Super	298
Well's	29
Bagga	7
Go Natural restaurants	1
Note!	6

2.4 Slaughterhouse and Meat Processing Center

The present section provides a deeper study of the **slaughterhouse** and the **meat processing center**, which are two important stages of the meat supply chain when it comes to understanding how meat by-products are removed from the bodies and are initially treated. In order to better comprehend these two stages, two establishments were visited by the author: Stec Raporal, a slaughterhouse which supplies meat carcasses to Sonae MC; and SoHi, a meat processing center that is responsible for the processing and distribution of beef, sheep, goat and pig meat products across many Sonae MC stores located in Portugal.

2.4.1 Stec Raporal

The *Stec Raporal* slaughterhouse, an entity that supplies pig carcasses to Sonae MC, was visited and is being described in the present section so that the process through which pigs go through before entering the Meat Processing Centre can be better comprehended. When a pig enters the slaughterhouse, it must go through the following stages [15]:

1. **Reception:** the pig is received at the slaughterhouse via a conveyor belt. The reception is only authorized after the pig has passed a rigorous health inspection test that ensures that the animal is free of bacteria present on the surface of the carcasses.
2. **Stunning:** the animal is stunned by an electric shock where they are charged around 600V for a duration of 2 seconds.
3. **Bleeding**: in this step, a knife incision is made, and the blood is collected in an appropriate tray for blood drainage. After the collection, the animal is hung.
4. **Carcass wash:** at this stage, the animal is washed in order to remove the soiling from the bleeding.
5. **Burning:** this process is done at 60 degrees Celsius and can be applied to several pigs simultaneously and lasts approximately 8 minutes. The purpose of this step is to prepare the carcass for epilation**.**
6. **Epilation:** in this step, both nails and hair are removed.
7. **Preparation of the extremities for suspension:** in this stage, the cutting of the members is carried out so that the animal can be then hung.
8. **Anus cut:** an anus cut is made, and the tubules are removed.

9. **Evisceration:** in this stage, a vertical cut is made in the carcass, the white viscera are removed and placed in the line of the viscera baskets, and the red viscera which are placed in properly identified cars. All viscera pass a veterinary inspection point for approval. The viscera always walks alongside with the carcass from which they were removed, thus being their traceability maintained.
10. **Carcass cutting:** in this step, a saw is used to separate the carcass into two half carcasses, through a longitudinal cut.
11. **Inspection:** after cutting, an inspection is carried out in order to verify the requested sanitary conditions.
12. **Head removal:** preparation of the head for its removal in the cutting room.
13. **Lard separation:** step whose objective is to remove excess fat and kidneys, which are then prepared in the cutting room.
14. **Labeling:** identification and classification of the carcass and by-products in order to maintain traceability.
15. **Sample collection:** samples are collected regularly and subsequently tested in the laboratory in order to guarantee sanitary conditions.
16. **Rib cutting:** making a cut in the ribs.
17. **Final washing:** rinsing the carcass to remove any potential contamination that occurred along the evisceration line and other operations
18. **Expedition:** both carcasses and by-products leave the slaughterhouse according to orders placed

In the case of *Stec Raporal*, the ending products leave the slaughterhouse within refrigerated vehicles that have temperature control devices so that they can be distributed to clients. The products can either be sold to clients that want to purchase them or they can be processed by processed by *Stec* itself. It is important to mention that *Sonae MC* only purchases pig carcasses from the above-mentioned slaughterhouse, but there are also many clients who purchase by-products from *Stec.* For example, *ITS* and *Sebol* purchase many animal by-products from *Stec,* such as tubules, kidneys, lungs and tongues.

2.4.2 SoHi’s Meat Processing Centre

In January of 2017, Sonae MC and Hilton Food Group, a specialist in meat preparation and packaging services, have established a joint venture agreement for the development of value-added beef, sheep, goat and pig meat products in Sonae MC stores in Portugal.

The partnership was developed through a society called SOHI Meat Solutions – *Distribuição de Carnes, S.A.,* which resulted from the 6 months pilot project in the Meat Processing Centre of Sonae MC, in *Santarém* (CPC, from the Portuguese name *Centro de Processamento de Carnes*). This partnership was an opportunity for Continente to improve the products’ quality delivered to consumers, to lead innovation in the food retail sector in Portugal and increase value in the meat sector, reinforcing the commitment to support the national production’s sustainable development. Under the agreement, Sonae MC and Hilton Food have worked together to improve the Meat Processing Center as a whole, which is currently responsible for the weekly supply of over 1.000 tonnes of meat to *Continente* stores in Portugal [17].

Sonae’s Meat Processing Centre (CPC) aims to process all the meat (beef and pig meat) that enters through the front door while creating the possible minimum amount of waste. Here, the meat enters according to a PBS policy, where to the picker is provided one order made by store at a time and then goes collect each item on the list until the order is complete [18]. Pig meat and beef can go through the following stages: Reception, Cutting section, Storage section, Production section and the Expedition. There are other two stations through which pork and beef do not pass directly but create a huge impact on the quality of the meat distribution: one is the zone where all the packing related materials are stored; the other one is the section that receives other types of meat different than pork and beef (poultry meat) that will later be distributed and are here handled in a cross docking flow. There are many issues within the management of CPC´s operations that need to be discussed, such as hygiene, all types of costs involved, energy waste, labor conditions and more.

Firstly, the sheep, the pork and the poultry meat are received in the **Reception** area. In this stage all the meat is analyzed (as the workers visually search for anomalies) and weighted to make sure that all the inbound requirements are fulfilled. The ones that pass the test get a green tag, meaning that these can go to the next stage. The ones that fail the test are returned to the supplier. It is important to stand out the fact that all the equipment is regularly tested in terms of hygiene and quantity of adherent oil. After going through this section, the meat can go to the Storage section or directly to the Cutting section.

The **Cutting** section receives, on a daily basis, between 70 and 90 tons of meat (carcasses and goat meat in the festive seasons). Here is where the carcass is divided into pure meat (pork) and all the by-products (bones, ears, fat, gammon, trimming, chop, and so on). This station is known for having a rolling carpet on which the carcasses lay on while the workers cut the meat with the help of all the specialized machinery. In this stage, the by-products go to different containers according to their respective categories. Each by-product can be considered fresh, if it is already ready to be distributed to clients; waste, if it cannot be used for anything; frozen, if the by-product has to be frozen to be later distributed. One must keep in mind that fresh products are always preferred, because the existence of frozen products generates high economic and energetic spending.

The **Production** section is the zone where the meat (which is already separated from all the by-products) is treated so that it can be later be packed for expedition. There are two main compartments: one where the meat is sliced in isolation from any other condiment; the other where the meat is sliced and mixed with other condiments (such as pineapple, onion, peppers and others) or simply minced meat. It is important to mention that the machine that produces mixed meat kebabs is conducive to produce errors, thus needing a lot of human effort in order to correct those errors. In the case that the meat is too damaged, that same meat becomes a by-product because it loses commercial value. Pieces of meat that contain anomalies (like abscesses, for instance) or metallic pieces immediately become waste.

Right after the Production compartments, there is a large robotic arm surrounded by protective grills for security reasons. This robot can read codes placed in the totes used to contain the Production products and separate all these totes according to their final use (cutlets, slices, minced meat, kebabs and more). The products can be packed in two types of packages: in vacuum, in which products can last 28 days without expiring; in nature packages, which are used for cases where the meat is lately packed within a nitrogen-rich air.

The **Storage** station is the place where all the frozen products are. Firstly, the products must go through a highly ventilated freezing tunnel (often at -40ºC) before actually being stored. The Storage place may receive products that come directly from the Reception and products that come from the Production area that will be in stock. In the case that the product stays too long in the storage room, the product expires and loses all its value, thus becoming food waste.

It is still important to mention the existence of two important CPC zones. The first one is the room where all the packing related materials (packages, films, tags and many more) are kept in. This zone has a much higher temperature than all the other rooms where the meat is treated. The main reason is that it also includes the sanitation facility that washes and cleans totes that circulate through stores and then return to CPC's process. This procedure uses hot water to ensure a deep cleaning of the containers. The second zone consists in a sort of Cross-docking area that receives products, other than beef and pork (poultry meat), that are then distributed according to their respective destiny without receiving any kind of treatment. The poultry meat is received according to a PBL (pick-by-line) policy. PBL is very similar to a true cross-docking policy. The difference is that PBL includes a step to break down the received pallets received from the suppliers by distributing the required cases into customer delivery containers which are then put in a grid on the warehouse floor (each marked area corresponds to an order that was placed by a store). Afterwards, the products are ready to be expedited [19].

Finally, after the meat is packed, this is sent to the **Expedition** zone. In this area, the products are grouped according to their respective final store location – the ones listed in Table 1 (which can be in the Mainland Portugal and sent by truck, or in Madeira, sent by ship). This zone is known for the high-speed movement of the products at the expedition periods. In Figure 4, the mapping of the CPC's processes can be observed.

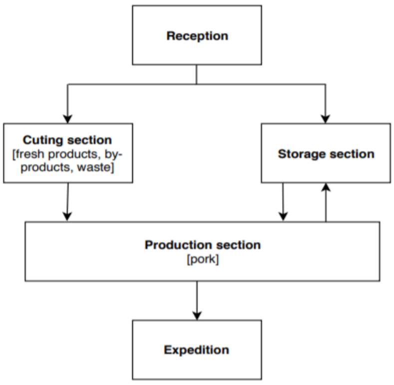


Figure 4 - Mapping of the CPC's processes

The management of all the operations in the CPC asks for the consideration of many issues and trade-offs. There is an issue that always must be kept in mind: the hygiene. This has been a very respected issue, since the lack of hygiene can seriously damage the products, thus putting the health of all consumers in danger. The CPC takes measures that promote the highest level of hygiene on the daily basis: everyday, between 1 a.m. and 5 a.m., the entire building is cleaned while all operations stop.

One very important trade-off is the one that exists between the speed and the accuracy of all operations: the higher the speed of all machines, the faster is the whole process, but the higher is the probability of occurrence of mistakes.

The biggest challenge of the CPC is the constant struggle against time. If there is any delay in the whole process, the products will not be distributed as they were supposed to, which can make the demand unmet and surpass the expiration date of some products, thus losing money.

The regulation of the temperature is also a big challenge, since all products need be constantly in a very low temperature environment, which can be a big issue due to energetic failures. Another issue that also must be kept in mind is the labor conditions, since the workers are constantly within very hostile environments (temperatures below 0ºC).

The main goal lays on the reuse and valorization of by-products and food waste while getting around all the obstacles mentioned above. Knowing how to value by-products by finding new markets where they can be valued is one of the main desires of existing companies in the industry being studied. The question is whether those market opportunities can offset the costs inherent in processing products or not.

2.5 Sonae MC's stores

Regarding the meat flow, there are many activities that must be performed in order to handle the meat that reaches the stores. Such activities can be divided into the following stages: Reception, Storage, Replacement and Waste treatment.

The **Reception** of all products happen between 10 pm and 12 pm or very early in the next morning, depending on the store. When the truck containing the products arrives to a store, it must go through several steps: (i) registration and show the confirmation seal; (ii) temperature verification, where the temperature has to be between 5 and 6 degrees Celsius in order to get into the store (iii) verification of truck cleanliness and maintenance status; (iv) unloading of the products, done by the driver, and then taken to the backroom by two or three operators from the corresponding section. The vehicle may bring combined products.

The **Storage** in the chambers is done according to FIFO (First in, first out) policy. Validity control is purely visual, as it is done by checking expiration labels, and pig meat being controlled according to its appearance. This happens because such products do not come packed without any information regarding expiration dates. Depending on the size of the store, there may be several chambers dedicated to the flow of meat. For instance, there is a store in *Telheiras* that has a chamber dedicated to poultry eat, other dedicated to other types of meat, and finally another dedicated just for by-products.

The **Replenishment** is usually done at times with higher demand, where they can pack and put meat with certain cuts at the front section of the store, in quantities according to their demand forecasts. These parts are valid for 1 day only as it is not possible to carry out laboratory tests at the back of the store to ensure food safety.

The **Waste treatment** is performed on trimmings resulting from the preparation of meat in the butcher's section and non-linear products which are no longer fit for sale due to validity or appearance. Meat shavings generated in the butcher's section are placed in plastic bags and placed in a container they have in the section and usually at the end of the shift are deposited in the specific zone for animal-based by-products. The by-products' chamber cannot be close to the butcher's section in order to minimize the risk of accidentally selling a by-product to a client.

Some data regarding FLW between the 13th and the 26th of November 2019 was provided by Sonae MC. By filtering the data, it was possible to get values regarding the wasted quantities of numerous types of meat (Poultry and rabit meat; Beef; Easy kitchen; Sheep and goat meat; Pig meat). The destinations for meat that Sonae MC considers are donation, re-use and improper (which means that the meat will not be re-used nor donated). In Figure 5, costs regarding all unsold meat between the 13th and the 26th of November 2019 are presented.

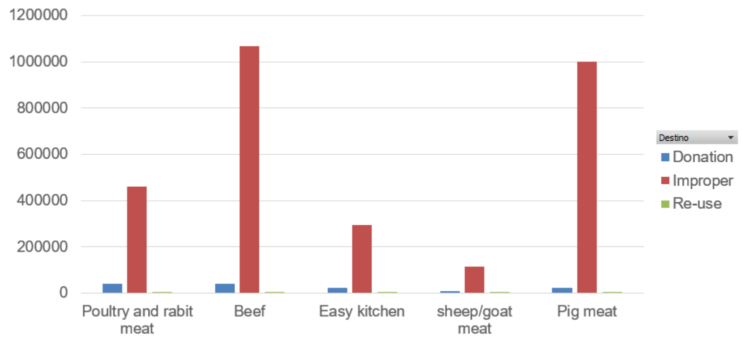


Figure 5 – Costs (€) of unsold meat and its destination

As it can be observed, the unsold meat was rarely re-used and most of them had an improper destination. Just regarding the improper destination, the beef and pig meat have alarming values of 1 068 599.08 and 999 190.26 euros, respectively, which is a clear sign of unsustainability and poor management. Regarding quantities (in kilograms), the values for the same destinations, types of meat and time frame are presented in Figure 6.

Figure 6 – Quantities (Kgs) of unsold meat and its destination

As it can be again observed from Figure 6, most of the wasted meat has improper destination. Just for improper destination, 63 951 kilograms of pig meat were wasted. The need for understanding the cause of such enormous quantities of wasted meat becomes urgent.

Considering the high values of meat wasted by all Sonae MC insignias, the idea of aggregating the stores according to insignias and respective zones seems quite sensible. The values of the aggregated unsold meat are presented in Figure 7. Sonae MC decided to aggregate stores according to insignias (*Continente Bom dia*, *Continente*, *Modelo* and *Meu Super*) and Portuguese regions. By looking at Figure 7, it becomes clear the urgency associated with the overwhelming quantities of wasted meat within only approximately two weeks. There is an opportunity for Sonae MC to collaborate with other companies to collect meat waste from numerous store clusters.

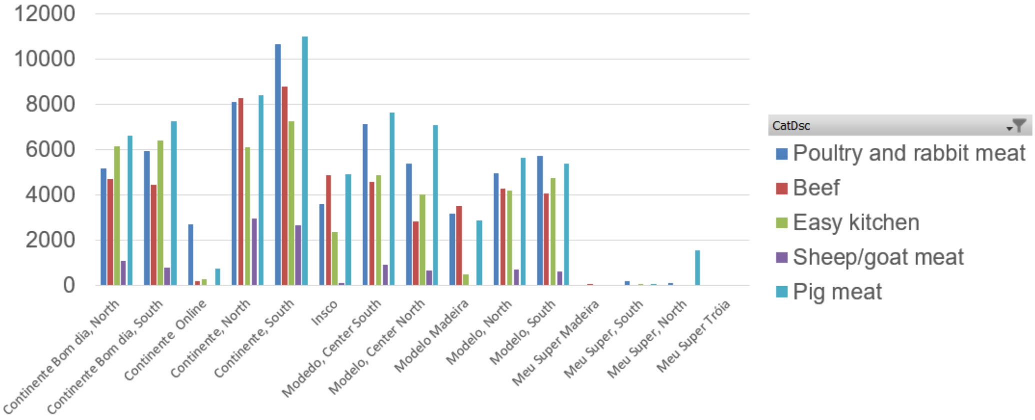


Figure 7 - Aggregated quantities of wasted meat (in kilograms)

2.6 Problem statement

The goal of this final section of Chapter 2 is to demonstrate the complexity associated with the problem on which the present work is based. As it was possible to analyse in the previous sections, the need for reducing meat waste, or, at least, reducing the meat quantity that goes to improper destinations becomes quite urgent. Since pig meat is the most wasted meat, it was decided that pig meat would become the focus of the present dissertation. The result we seek to obtain will be to find new opportunities to reduce the quantity of unsold pig meat and add value to pig meat that is unsold, wasted or lost.

Also, there is the urge for new opportunities to aggregate pig meat waste by location so that relevant quantities can be collected regularly since the waste is geographically dispersed. This requires collaboration between entities operating throughout the meat supply chain. With that in mind, the present work will be developed by exploring the idea of partnership between companies belonging to the PPS-7 in order to collect pig meat waste and add value to it. The complexity of the problem mainly relies on how to capitalize on opportunities to add value to unsold meat while getting around associated with the meat industry (including meat legislation and all other characteristics mentioned in section 2.1 regarding the meat sector).

In the context of the present dissertation, the work will be exclusively focused on pig meat by-products from slaughterhouses. This is because of two main reasons. Firstly, in those stages, there are fewer collection points (and, therefore, a higher quantity of fresher by-products to collect in each point) than there would be in the case of by-products' collection from stores. Secondly, and most importantly, such pork by-products that can be found in larger quantities in slaughterhouses and meat processing centers are the most commercialized and consumed ones in China, as it can be observed in Figure 20, in section 4.2.1.1 (the most important features of the Chines pork market will be deeply explored in section 4.2.1.1).

The goal will be, therefore, to collect pig meat by-products from slaughterhouses and add value to them. In the context of this work, those infrastructures that will serve as collection points are located in Lisbon, Tagus Valley and in the central region of mainland Portugal. This is because, as there is a large airport and also a maritime port in Lisbon, only the Abapor's infrastructure that is located in Loures will be considered (Figure 3). Also, because most of the Portuguese slaughterhouses are located in those regions, the other three Abapor's collection points were not considered in this work.

In this work, the value will be added through the export of pig meat by-products to China, a country whose culture will enable a better destination for such products (as the reader will better understand in section 4.2.1.1), which otherwise would be wasted. The following chapters will, not only highlight even more the urge for finding ways to recover meat waste, but also provide innovative ideas that value those products, by providing proper destinations, while all collaborating stakeholders benefit from it.

2.7 Chapter conclusions

This chapter provided the context on the problem being studied, with the presentation of the *MobFood* Project, as well as the PPS-7 and some of the constituent entities. In that sense, the main point of this chapter was to provide information about the problems being faced by the project, as well as the role of each company belonging to the PPS-7 that acts in the meat sector. Because the comprehension of the processes related to the treatment of pig meat is crucial in order to find new opportunities to value meat residues and by-products, the meat flows within the slaughterhouse, the Meat Processing Center, Sonae MC stores and also throughout the collection process performed by Abapor were described. Each presented company acts with a distinct approach by providing new ideas and perspectives. The objective of this work is therefore to find opportunities to add value to meat by-products.

3. Literature review

This chapter aims to present all the necessary knowledge and theoretical basis to understand and face the problem that is being analyzed in this dissertation, which will be based on agri-food waste, especially meat waste.

This chapter starts with an explanation of the agri-food industry in the EU in Section 2.1. In this section, the agri-food industry is characterized as it presents what is currently happening in the industry. It also presents drivers for enhancing sustainable development for the agri-food industry, as well as some of the most relevant initiatives, are presented. This section also exhibits the most relevant legal aspects of the agri-food industry (especially meat), in the EU context and in the Portuguese context. In section 2.2, the FLW context worldwide is explained, but especially in the EU. This section starts with the contextualization of the FLW. Then, it explains the problem regarding the lack of a common shared definition for FLW. Thirdly, the main causes for FLW are demonstrated. Right after, the most common FLW common destinations, as well as a hierarchy for them, are presented. Then, an explanation regarding the most used methods for meat by-products recovery is exhibited. Then, a study of FSC collaboration among agri-food industry stakeholders is presented. Finally, an analysis of concepts related to optimization models, more specifically, the ones related to Vehicle Routing Problems, is exhibited as well.

The keywords used to collect the documentation presented in this chapter were: Agri-food Industry; Food supply chain waste; Meat waste; By-products recovery; Sustainable collaboration; Food loss and waste prevention measures; Food loss and waste causes; Legal aspects of the Agri-food industry; Food sustainable development; Vehicle Routing Problem; Waste Collection problem. Documentation and legislation from the European Union were collected directly from their websites and repositories. Scientific publications were collected from directed searches in scientific databases such as Web of Knowledge, Science Direct and Google Scholar. As each of the presented keywords were searched for individually, the documents that were visited first were the most cited ones. Therefore, all the information that is displayed throughout this chapter is based on the most cited documents and the most popular websites.

3.1 Agri-food Industry

This section is dedicated to the study of the Agri-food industry. Firstly, this industry will be characterized as it aims to demonstrate how important it is to preserve it and to promote sustainable development. That is why sustainable development is addressed in this section. Then, the most relevant legal aspects will be presented, showing how regulated the agri-food industry is regarding hygiene and safety for food.

3.1.1 Agri-food Industry characterization

The agri-food industry is referred to as the business of producing food agriculturally. It is linked to the chain of events from production, processing and distribution to consumption [24]. At a European level, according to the European Commission (2018), agri-food related services employ almost 44 million workstations in the European Union (EU), being the food production and processing responsible for 7.5% of employment and 3.7% of the total value that is added. Additionally, according to FoodDrink Europe [25], the EU food and drink industry employs 4.57 million people, thus being the leading employer in the EU. Phil Hogan (2018), Commissioner for Agriculture and Rural Development, confirmed that, in 2018, the EU reached a value of 138 billion euros of exports and 116 billion in imports [26].

In Portugal, due to its favorable climate and agriculture, agri-food and beverages are the most important pillar of the Portuguese economy. The sector includes the production of goods that come from agricultural crops, cattle raising, fishing and the production of vegetables, fruit, meat, oil crops, dairy products, wine, olive oil and others [27]. After Portugal joined the European Union, the sector had to adapt to all European production and presentation standards, including labelling, hygiene and additive rules. Nowadays, the Portuguese agri-food industry is one of the most developed sectors and it is consistently growing [28]. According to Jorge Henriques, president of *Federação das Indústrias Portuguesas Agro-Alimentares (FIPA)*, the Portuguese agri-food industry's business volume will surpass the 19.000 million euros mark by the end of 2019, from which 5.000 million euros will be due to exportations, thus representing 19% of the total transforming industry in Portugal. Additionally, the industry is composed by 11.000 companies and is responsible for 115.000 direct workstations and 500.000 indirect workstations [29]. According to FIPA's website, in 2018, the Portuguese agri-food industry reached 5.016 million euros and 7.287 million in exportations and importations, respectively [30].

3.1.2 Sustainable development in the Agri-food Industry

Considering the fast-growing population that we are all witnessing, the insurance of enough quantity, safety and quality of food for everyone is the biggest challenge in the agri-food sector [31]. However, a rise in food production is not enough, considering all the resources we have on earth. With that in mind, some of the main drivers of change were identified:

- The world food production needs to increase by 70% by 2050 in order to keep up with the exponential population growth, which is expected to reach 9.7 billion people (34% higher than it is today) [31]. This generates higher demand for more varied high-quality food while having limited resources to produce food. Additionally, many countries suffer from hunger and malnutrition [35];
- Price volatility of farm products has increased as a result of the higher frequency of extreme climacteric events caused by climate change. This makes production and market more unstable, which contributes to increased volatility [34];
- Food prices are rising and becoming less available, as FAO stated that we are witnessing the "new era of rising food prices and spreading hunger," noting that "food supplies are tightening everywhere and the land is becoming the most sought-after commodity as the world shifts from an age of food abundance to one of scarcity" [35];
- European citizens are consuming less healthy food that have too many calories, fat, sugar and salt, which means that there need to be changes in people's diet [35];
- Despite the existent under-nutrition in many countries around the world, it is estimated that one-third of all food produced around the world is lost or wasted, which amounts to 1.3 billion tons per year [35,36];
- There have been some changes recently in the food supply chain, in the sense that, over the last decades, it changed from a supply-driven supply chain to a demand-driven one, with bargaining power more concentrated in the retail sector, unlike primary producers, who have a subordinate economic role in the supply chain [35];
- According to the Environment Agency, about 75% of the most fish of high commercial importance are out of the safe biological limits;
- More than 1.4 billion people live where there is not enough water to satisfy agricultural, municipal and environmental needs;
- It is estimated that phosphorus' demand, which is an input to boost agricultural production, will increase between 50 and 100% by 2050. EU is highly dependent on the import of this substance, that is present in phosphate rocks, whose contamination is highly uncertain [35];
- Biodiversity levels are declining due to intensive agriculture and forestry practices used to increase the provision of food and biomass-based fuels [37].

With all the above-mentioned drivers of change in mind, we must act in a sustainable way. Sustainable food production is referred to as "a method of production using processes and systems that are non-polluting, conserve non-renewable energy and natural resources, are economically efficient, are safe for workers, communities and consumers, and do not compromise the needs of future generations" [32]. Sustainability has three major pillars: economic sustainability, social sustainability and environmental sustainability. The economic dimension is related to commercial or fiscal viability of all activities conducted by every food actor. These activities should consider the financial wellbeing of all stakeholders involved: wages for workers, taxes for governments, profits for enterprises, and food supply improvements for consumers. The social dimension is concerned with how well distributed the economic added value through the entire population is, considering gender, youth, indigenous people, cultural traditions, nutrition and health, workers' rights and safety, animal welfare and so on. The environmental dimension to how food systems impact the earth, considering biodiversity, water, soil, animal and plant health, the carbon footprint, the water footprint, food loss and waste, toxicity and other environment-related issues [33].

The need for promoting sustainable practices where all stakeholders around the world are involved is urgent. FoodDrinkEurope and its members have been highly committed to the UN Sustainable Development Goals (SDGs) since 2015, which are a set of 17 goals (see Figure 8) with 169 targets and are included in an agreement made by all developed and developing countries mobilizing governments, institutions and stakeholders called the UN 2030 Agenda for Sustainable Development Goals. However, all these sustainable initiatives can not be implemented independently and require collaborations and partnerships along all the food suply chain and all stakeholders that can make a positive impact on sustainability. With that in mind, cooperation between all the involved stakeholders is the key for implementing successfully all the above-mentioned initiatives. That is why FoodDrinkEurope implemented the **Commission high-level multi-stakeholder platform**, which is the basis for communication between the stakeholders, the implementation of meetings, for giving support and advice and give feedback on the implementation of the SDGs in the EU so far [38,39]. There are two SDGs to which it will be given special attention due to the context of this dissertation: the **Zero Hunger** SDG and the **Responsible Consuption and Production** SDG.

Figure 8 - UN Sustainable Development Goals [38]

Regarding the second SDG, **Zero Hunger**, the main objective is to end hunger, achieve food security and improved nutrition and promote sustainable agriculture [40]. Food and drink companies play a very important role in the implementation of this goal, as they are the ones that can ensure **food supply chain sustainability**, thus being FoodDrinkEurope highly committed to this SDG. Food security is a real challenge that every food and drink supply chains face these days, due to climate change. All the instability related to climate change not only affects food production levels but also price stability. Hence, agri-food companies must be always looking for strategies to become more sustainable, competitive and productive. The second SDG pays special attention to agricultural productivity, production and farmers' income, maintaining ecosystems, agricultural markets and trade rules [40].

Regarding the twelfth SDG, **Responsible Consumption and Production**, it is intended to enhance resource-efficiency and circular economy applied to the food supply chain. These two concepts are beneficial for all societies and make great environmental and business sense since, in the context of the food supply chain, these mean preserving valuable resources like raw materials, water and energy for as long as possible. Avoiding food waste must be a top priority for food and drink companies, as they shall actively work towards reducing food waste along the supply chain by creating innovative collaborations. FoodDrinkEurope as also been participating actively within this SDG, by being a member of the Advisory board of the FAO-UNEP 10-year Framework of Programmes on Sustainable Food Systems and by being the founding member of the European Food Sustainable Consumption and Production Round Table (where FoodDrinkEurope created a protocol for a proper environmental assessment methodology for food and drink products with other food supply chain partners) [49].

3.1.3 Legal aspects of the Agri-food Industry

There is an overwhelming ammount of legislation related to food and specially meat, most of what is currently in place followed by the bovine spongiform encephalopathy crisis that took place in the mid-1990s. Since then, the food sector has become one of the most regulated sectors. The food legislation can be divided into three categories: product legislation, process legislation and presentation legislation [45]. The structure of the food law in the EU can be observed in Figure 9. By looking at Figure 9, it becomes intuitive to understand that the food law's main goal is to protect the life, health and other consumer-oriented interests. What makes food safe and healthy is the way food business entities handle food. Also, public authorities must ensure compliance between food business entities and copy with situations of non-compliance [45]. Food business companies must verify all product standards regarding the product itself (product quality standards, food safety), the processes (mostly hygiene traceability) and miscellaneous issues (for instance, the materials in contact with food). Public authorities are the ones in charge of making decisions regarding the implementation of measures, food control, risk assessment and incident management [45].

Nowadays, EU citizens have high expectations regarding the safety and quality of the food they eat. Modern food systems must be able to provide full transparency, not only regarding animal health and food quality and safety issues, but also environmental issues and animal welfare. In order to meet these high expectations, the EU has established a fundamental food safety legislation. The EU food laws pay attention mostly to the management of quality and process controls along the entire food supply chain, that is, from farm to fork [41]. In 2002, the **Regulation 178/2002 of the European Parliament and of the Council of 28 January 2002** was created. This regulation intends to demonstrate the general main requirements of the food law, establish the European Food Safety Authority and all procedures that lead to food safety. This regulation is often called "The General Food Law" [45].

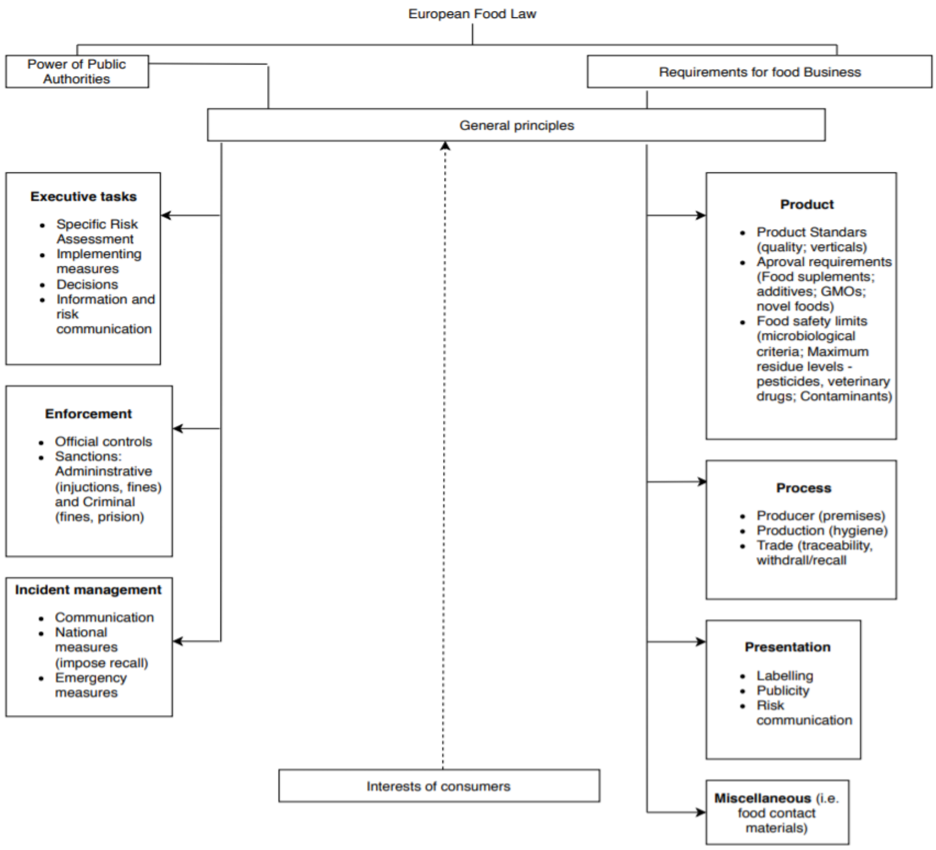


Figure 9 - Structure of the food law in the EU. Adapted from Van der Meulen (2013) [45]

After the General Food Law, many more legislation packages were created. The most relevant ones can be observed in Table 2.

Within the agri-food industry, the meat sector will be more deeply discussed in this dissertation. This last sector is so regulated because the assurance of good quality and of the meat being sold is crucial for consumers' health and wellbeing. A group of the most relevant EU regulations, which were not already mentioned in Table 2, concerning the meat sector can be listed:

- **Regulation (EC) No 1760/2000 of the European Parliament and of the Council of 17 July 2000** that establishes a system for the identification and registration of bovine animals and regarding the labelling of beef and beef products and repealing Council Regulation (EC) No 820/97;
- **Regulation (EC) No 854/2004 of the European Parliament and of the Council of 29 April 2004** laying down specific rules for the organization of official controls on products of animal origin intended for human consumption;
- **Commission Implementing Regulation (EC) No 931/2011 of 19 September 2011** on the traceability requirements set by Regulation (EC) No 178/2002 of the European Parliament and of the Council for food of animal origin;
- **Commission Implementing Regulation (EU) No 1337/2013 of 13 December 2013** laying down rules for the application of Regulation (EU) No 1169/2011 of the European Parliament and of the Council as regards the indication of the country of origin or place of provenance for fresh, chilled and frozen meat of swine, sheep, goat and poultry (Global Sntandars One (GS1), 2015) [46].

Table 2 - The most relevant food legislations. Adapted from Van der Meulen (2013) [45]

Year	Legislation
2002	Regulation 178/2002 (General Food Law)
2003	Regulations 1829/2003 and 1830/2003: GMO (Genetically Modified Organism) package
2004	Regulations 852–854/2004 Hygiene package, Regulation 882/2004 Official controls, Regulation 1935/2004 Food contact materials
2005	Allergen labelling requirements included in Directive 2000/13.
2006	Regulation 1924/2006 Nutrition and health claims
2007	White Paper A Strategy for Europe on Nutrition, Overweight and Obesity related health issues
2008	Regulations 1331–1334/2008: Food Improvement Agents Package (FIAP); additives, flavourings and enzymes
2011	Regulation 1169/2011 Food information to consumers

Regarding imports of food - from ouside the EU to the EU - it has to get through many safety and quality control tests before reaching the consumer and the exporting food operator must comply with all the food principles present in **Regulation 178/2002/EC** [42]. More specifically, for fresh meat, **Council Directive 2002/99/EC** contains all legal basis for all animal health rules governing the production, processing, distribution and introduction of products of animal origin for human consumption [43]. The meat has to be tested by legitimate and adequated empowered authorities in the exporting country. These authorities must ensure credible inspection tests throughout the food supply chain, which include all relevant aspects of hygiene, animal health and public health. All negotiations must be between the competent authority belonging to the export country – official veterinarians - and the European Commission, which means that if a private business entity from a non-EU country wants to export meat to the EU, it must contact the competent authority belonging to that same country, who will communicate with the European Commission [18]. Fresh meat entering the EU is inspected at an EU Border

Inspection Post (BIP), where Member States' official veterinarians check if the entering meat fulfils all the requirements provided by the EU legislation, which are presented in **Commission Decision 2009/821/EC**. On the other hand, when exporting food and drink products to a Non-EU country, the EU country is the one that must be aware of all conditions and possible restrictions and setbacks, which must be guaranteed before the food is sent to the third country. In order to export food to a third country, the EU country must contact the authority of the destination country or their foreign embassy located in the EU country. Some third countries require food and drink exports to be certified. Each country has its specific requirements, which depend on the country itself and the product being exported [44].

In Portugal, most of the food related regulations are the same as the ones applied in all EU countires. However, some specific Portuguese regulations regarding food hygiene and labelling, butcher and slaughterhouse regulations must be pointed out:

- **Regulation 1935/2004**, regarding materials and objects in contact with food;
- **Regulation 853/2004**, which establishes specific hygiene rules applicable to animal foods [46];
- **Law No. 28/84**, which prohibits the slaughter of pigs outside approved establishments (Slaughterhouses), if they are destined for public consumption, making this practice a crime against public health [47];
- **Law No. 323-F/2000**, which establishes principles and rules for the labelling of beef and beef products;
- **Law No. 33/2017**, which ensures compliance with the provisions of Regulation (EC) No. 1069/2009, which lays down the health rules concerning animal by-products and derived products not intended for human consumption [59];

The main conclusion to take from this section is that the food sector is highly regulated, which makes sense, since to ensurance of safety and quality of the food we eat crucially influence all people's health. However, such strict regulations may lead to a lot of food waste and may bring restrictions to collaboration opportunities between entities along the food suply chain, as it will be more deeply explored in section 3.2.3.

3.2 Food Waste

This section is dedicated to one of the most complex challenges regarding FSC (Food supply chain) sustainability: food waste and loss. This section starts with a contextualization of the world food waste, in order to demonstrate how FLW impacts the environment, economy and society. Then, the complexity of the FLW definition and the lack of a commonly agreed definition for it will be exhibited. Right after, a list of causes for FLW in each stage of the FSC will be presented. Then, a list of the most relevant possible destinations for FLW, as well as a hierarchy for them in order to demonstrate which of them are the most favorable will be demonstrated. Finally, some preventive measures for recovering meat by-products will be exhibited.

3.2.1 Contextualization of the world food waste

Although chronic hunger has been reducing, there are still around 800 million people who suffer from under-nutrition, even though there is enough food production to feed the entire world [50]. At the same time, it is estimated that one third of all food produced is being lost or wasted throughout all food supply chain stages - from production to consumption - which means 1.3 billion tones/year or a quarter of calories destined for humans [51]. Moreover, wasting food means more than lacking life-supporting nutrition: it means wasting scarce resources like land, water and energy that were expended in production, processing and distribution [55]. Food loss and waste (FLW) generates tremendous inneficiency when using the available resources: 1.4 billion hectares of agricultural land, which is 30% of the world's agricultural land area is wasted [52]. A study developed in 2010 by the European Commission states, by using EUROSTAT available data, that, just in the EU, 89 million tonnes are wasted annually, which means 179 kg *per capita* on average [53]. This data shows, not only **unethical behaviour** (since millions of people from developing countries suffer and die from starvation while consumers from developed countires waste food at home and in restaurants on a daily basis), but also ineficiency from consumers and all other food supply chain entities in **food security, economy and environment** aspects.

Regarding **food security**, FLW impact food security in three main ways. Firstly, FLW reduce food availability of food for consumers. Secondly, FLW create a negative impact on food access, not only for workers involved in harvest and post-harvest activities (due to FLW-related income losses), but also for consumers (who contribute to tight the food market and raise prices). Thirdly, in a longer-term context, FLW results in unsustainable use of natural resources that are limited on earth and are needed for future generations [56]. The causes of FLW vary from low-income developing countries to medium and high-income countries: in developing countries the causes occur mostly in the harvest and post-harvest stages of the food supply chain and are mainly related to insufficient farmers training, the lack of technology and infrastructural limitations such as harvesting techniques, storage and cooling facilities, transportation, and packaging and marketing systems; whereas in the developed countries the FLW occur mostly in the distribution and consumption phases and are mainly due to lack of coordination between different actors in the supply chain, as well as consumer behavior. Nonetheless, it is important to mention that FLW from agricultural production to consumption causes happen in both developing and developed countries [57].

Considering the **economy**-related issues, it is intuitive to comprehend that FLW causes negative effects on every country's economy. According to the FAO (2018) report, the market value associated with FLW was estimated at 936 billion US Dollars in 2012, which is slightly larger than the GDP of Indonesia or the Netherlands for the same year [51]. On one hand, the cost of lost or wasted good is added to the final consumer price, making it harder for lower-income consumers to access food markets. On the other hand, an FLW cost represents an inflated demand that pushes the supply side to produce more than what is necessary, contributing to an inflated and unsustainable food system [51]. However, some attempts have been made to study the effects of reducing waste on food prices. In a first scenario, standard economic theory suggests that reducing food waste could increase supply and move the supply curve to the right, thus lowering prices and increasing consumption. In an alternative scenario, reducing food waste could decrease demand and consumption, thereby decreasing quantities and prices. Very little is known about the impact of changes in levels of food waste on welfare gain or loss or on the magnitude of the impact of price levels on food waste [57].

Regarding the **environment**, it must be mentioned that FLW also means energy waste, water waste and GHG release. FLW-related energy is responsible for approximately 38% of the total energy consumed throughout the whole food supply chain [51]. Considering GHG emissions, FLW is accounted for the release of 4.4 Gtonnes of CO_2 or about 8 % of global GHG emissions [60]. Only considering CO_2 emissions, if FLW were a country, it would be the third major emitter on Earth, being just behind the United States of America and China [61]. Regarding water wastage, FLW was responsible for a global water footprint of 250 km^3 in 2007 or 20 percent of freshwater consumption [51]. It is important to highlight that animal products usually have a higher water footprint per kg of food production due to the large amounts of water required to grow animal feed crops. Improvements must be applied to agricultural activities because 70% of the total water consumed in the world corresponds to the agricultural stage [58] and the largest consumption of resources and the highest greenhouse gas emissions per kg are caused by meat products, of which beef products are most critical [59].

In the EU context, the European Commission estimated in 2012 that between 30% and 50% of edible food was wasted throughout the food supply chain, representing 88 million tons of FLW. In 2012, the EC published the values presented in Table 3 in the context of the FUSIONS project [53].

Table 3 - Estimation of FLW in Europe in 2012. Adapted from CNCDA (2017) [53]

Sector	FLW (million tons) [1]	FLW (Kg/person/year)[1]
Primary production	9.1 ± 1.5	18.3 ± 3
Industry/ PROCESSING	16.9 ± 12.7	33 ± 25
Wholesale and Distribution	4.6 ± 1.2	9 ± 2
FOOD SERVICE/Catering[2]	10.5 ± 1.5	21 ± 3
Families/ HOUSEHOLDS	46.5 ± 4.4	92 ± 9
Total	**87.6 ± 13.7**	**173 ± 27**

[1] Values have a Confidence Interval of 95%

[2] It includes hotels, restaurants and cafes

In order to get a better perception regarding the relative distribution of the FLW along the food supply chain, it is represented in Figure 10 the split of EU-28 FLW in 2012 [62].

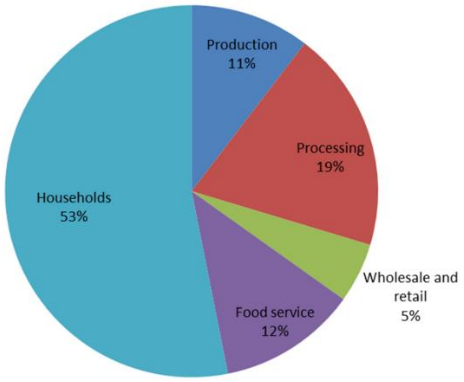


Figure 10 - Relative distribution of the FLW throughout the FSC in 2012 [62]

In the Portuguese context, a developed study called PERDA (‘*Projeto de Estudo e Reflexão sobre o Desperdício Alimentar*’), estimated that nearly 17% of edible food parts produced for human consumption are lost or wasted in Portugal along the whole food supply chain until they reach the consumer, which represents 1 million tonnes per year, thus corresponding to 96,8 kg *per capita* [53,54]. The authors of the report ‘*Do Campo ao Garfo*’, by interviewing 70 food producers, industry workers and retailers and by developing an inquiry where 804 families responded, they were able to do an estimation of FLW quantities throughout the food supply chain (Figure 11) in one year [54].

Figure 11 - FLW in Portugal in one year. Adapted from [54]

As it can be observed, the most efficient food supply chain step is the processing phase (second step) where FLW are minimized and reused in other processes, whereas the initial and final steps are where FLW reach the highest values. According to the same report, in Portugal, meat accounts for 10% of the FLW along the food supply chain. The most consumed meats are pig and poultry meats. Mortality and disease are the main causes of meat loss in production. The existent losses in transportation and in the slaughterhouse stage are very little. Processed meat is that is wasted is almost exclusively pig meat. The meat industry is considered highly economic, since everything that is considered edible is used, thus being routed to their respective processing line. Most of the losses occur in the final stages of the supply chain - distribution and consumption [54].

3.2.2 Definitions for food loss and waste

The absence of a universal well-defined concept of FLW is a big obstacle to get access to accurate data regarding FLW and to start developing preventive measures using collaboration. Finding a commonly agreed definition for FLW is the key to measure it in a coherent way across all sectors and countries. As it is known, a number of current on-going initiatives are attempting to achieve consensus on such definition, some from different perspectives. While the existence of these initiatives is a positive indication of the momentum on food waste prevention and reduction, entities should not compromise future by using incompatible results [57]. For instance, the European Commission does not provide a food waste nor a food loss definition. The fact that there are so many different definitions for FLW results in different estimations for FLW volumes, current impact, and potential solutions [51].

FLW can be expressed in calories, weight, volume or monetary value, all depending on the specific question to be addressed. When different sectors of the food chain are combined, it is extremely hard for different entities to compare data and collaborate due to differences in scope [57]. The fact that there are so many studies that use deviating metrics (for instance, tonnes of food waste per year, sur-plus calories per person and day) and refer to different research subjects, such as different stages of the food chain, different product groups or different geographic units (for instance, cities, regions, federal states) results in discrepancies in data stock and makes it really difficult to compare results and for entities to collaborate. Thus, more systematic research on FLW is highly needed, so that it is possible to implement appropriate mitigation strategies and monitor their progress [59].

First, a clear distinction between **Food loss** and **Food waste** is required. In the FAO (2018) report, food loss is defined as “the decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption”. On the other hand, food waste is part of food loss and refers to “food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil”. The difference between food waste and general food loss must be stressed due to distinct drivers that generate both, thus requiring different solutions. Food loss mainly happens throughout the food supply chain due to poor infrastructure, lack of adequate technology or access to markets, insufficient knowledge and management skills by the actors involved [51]. It must be stressed that in this case, FLW is only measured for food products that were originally destinated for human consumption, thus excluding animal feed or inedible food parts. So, all food products that were originally designed for human consumption that were unexpectedly taken off from the human food supply chain are considered FLW, even if those are latter used for non-food needs [51]. This creates the need for distinction between **planned** and **unplanned** food uses.

Generally, food waste or loss is measured only for products that are directed to human consumption, excluding feed and parts of products which are not edible. Per definition, food losses or waste are the masses of food lost or wasted in the part of food chains leading to “edible products going to human consumption”. This approach distinguishes “**planned**” non-food uses from “**unplanned**” non-food uses, which are accounted under losses [63]. Commonly, it is also made a distinction between **edible** and **inedible** waste. Inedible wastes are typically by-products obtained during production at farms or manufacturing, such as twigs, peels, stones, bones, offal and more. Edible waste is defined as the parts of the food expected to be consumed by humans, like tomatoes, meat, bread and so on [58].

The FUSIONS (Food Use for Social Innovation by Optimising Waste Prevention Strategies) report (2016) also gives a different and interesting approach for the definition of FLW by involving possible destinations for food in FLW quantification but not considering food or inedible parts which will later feed animals or be used for bio-based material/chemistry processing: “Food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed, including the following destinations: composting, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea but not including food or inedible parts of food removed from the food supply chain to be sent to animal feed or bio-based material/chemistry processing. In addition, packaging is not included in the food waste definition and shall not be taken into account in the food waste quantification” [62].

3.2.3 FLW main causes

In this section, the work developed within [64] will be highlighted, as the main points that are referred in that article will be presented. This article studies the main causes for FLW throughout the FSC. Three main contexts for the FLW main drivers were deduced in this work: **Technological**, **Institutional** and **Social**. The technological context refers to misuse, failures and limits of the current technology used in the FSC. The institutional context refers to the organizational aspects in the perspective of both public and private sector and is divided into two sub-contexts: **Business management and economy**, which refer to FLW drivers that depend on an organization's business choices and are determined by economic variables; and **Legislation and policy**, which refer to inefficient legislation applied in the food business that generate FLW across the FSC. Finally, the social context refers to consumers' behaviors and lifestyles when dealing with food [64]. All these causes explain the urgent need to study and solve FLW, which most of them occur due to inefficiency (in business management, legislation, or even at home).

Regarding meat, which is the main object of the present study, it was possible to take some of the main drivers of meat loss and waste. Firstly, the definitions of meat loss and waste, which vary according to each FSC stage can be listed [63]:

- **Agricultural production**: for bovine, pig and poultry meat, losses refer to animal death during breeding.
- **Post-harvest handling and storage**: for bovine, pork and poultry meat, losses refer to death during transport to slaughter and condemnation at slaughterhouse.
- **Processing**: for bovine, pork and poultry meat, losses refer to trimming spillage during slaughtering and additional industrial processing, e.g. sausage production.
- **Distribution**: includes losses and waste in the market system, that is, wholesale markets, supermarkets, retailers and wet markets.
- **Consumption**: includes losses and waste at the household level.

Additionally, it was possible to find some of the meat loss and waste main drivers in the article developed within reference [64]:

- Forecasting: livestock production always implies considerable time gaps between the planning of production volumes and when the products can be marketed (sometimes it takes several years).
- Current practices of industrial livestock farming in general cannot avoid a certain level of losses, even when the minimum legal standards on protection of animals are fulfilled.
- Inadequate systems of control in production and processing. Here are some examples: slaughtering and processing losses in the meat industry , cutting and trimming losses, losses due to production errors and rudimentary control measures, processing waste (for instance, pastry trimmings, overfilling losses) and failure of the heat seal on packaged food.
- EU regulations on food contamination by microorganisms, pesticides, or pharmaceuticals are blamed as FLW causes, because of the strict tolerance for residuals (for instance, for antibiotics and hormones on animal products)
- Food safety legislation sets restrictions on the use of animal residuals for food and animal feed preparations are often perceived as hindrances to FLW prevention and reduction
- The EU regulation for animal by-products has set the prohibition of feeding terrestrial animals with by-products obtained from the same species, feeding farmed animals with catering waste and its derivatives, and with forages obtained from the land where organic fertilizers other than manure have been applied.

3.2.4 Destinations for FLW

There is a big range of options for FLW destinations and they differ significantly. While some of them add value to FLW, that is, these options generate an output that is useful for some purpose, other options add no value, meaning that FLW become a final disposal. Two reports were used in this section in order to list a range of possible FLW destinations: the **FUSIONS report** (2016) and the **Food Loss and Waste Accounting and Reporting Standard** report (2008). The destinations proposed by both reports were compiled and are listed in Table 4.

As it can be observed from Table 4, there are many similarities between the FLW destinations represented by both reports. Now, a deep study of each possible destination is fulcral in order to understand which of the possible FLW destinations is the best-suited for a given case. Animal feed simply refers to diverting material from the FSC to animal consumption. Biobased materials and biochemical processing consist in transforming materials into industrial products (for instance, transforming rendering fat, oil, or grease into a raw material to make products such as soaps, biodiesel, or cosmetics). Codigestion/anaerobic digestion refers to breaking down material via bacteria in the absence of oxygen, which includes fermentation (converting carbohydrates— such as glucose, fructose, and sucrose—via microbes into alcohols in the absence of oxygen to create products such as biofuels). Composting/aerobic processes are basically breaking down biodegradable matter via bacteria in oxygen-rich environments and it is used for the production of organic material that can be later used as soil amendment. Controlled combustion (also called incineration) consists of sending FLW to a specially designed facility in order to apply controlled combustion, which may include energy recovery. Land application refers to spreading, spraying, injecting, or incorporating organic material across some land surface in order to get better soil quality. Co-generation simply consists of combining heat and power from incineration. Landfill refers to ending material to an area of land or an excavated site that is specifically designed and built to receive wastes. Refuse/discards/litter simply refers to abandoning material or disposing it off in the sea (it includes open dumps, open burns and so on). Sewer/wastewater treatment includes all the materials that go down the sewer (with or without prior treatment) and also the ones that go to designed to treat wastewater facilities [62,65].

However, making a list of all possible FLW destinations is not enough, thus being a hierarchy development regarding those destinations required. The destination that is chosen must be the best suited one for the specific FLW being handled, taking into account the materials involved, the pollution that is caused, the available budget and so on. The most adopted waste hierarchy is presented in Figure 12.

Table 4 - FLW destinations from the Food Loss and Waste Accounting and Reporting Standard report and the FUSIONS reports

Food Loss and Waste Accounting and Reporting Standard[1]	FUSIONS Report[2]
Aninal feed	Animal feed
Bio-based materials/ biochemical processing	Biobased materials and biochemical processing
Codigestion/anaerobic digestion	Anaerobic digestion
Composting/aerobic processes	Composting
Controlled combustion	Incineration
Land application	Co-generation
Landfill	Landfill
Not harvested/plough in	Plough in / not harvested
Refuse/discards/litter	Discards
Sewer/wastewater treatment	Sewer

[1] [65]
[2] [62]

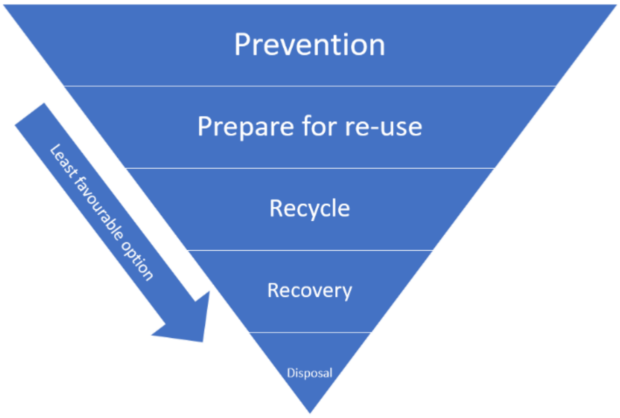


Figure 12 - FLW destinations hierarchy. Adapted from [66]

As it can be observed, Figure 12 shows the available options to deal with FLW, being the most favorable one on the top and the least one on the bottom. The aim of the hierarchy is to deliver the outcome that is the most environment-friendly depending on the type of FLW. Although this method has been adopted worldwide, it has been highly criticized by many authors due to the fact that it only considers environmental impacts, neglecting economic factors [66]. The most preferred option is **Prevention**, because it refers to avoiding the generation of FLW throughout the FSC and it is economic and friendly for the environment. Then, **Re-use** means using food surplus by distributing it to people affected by poverty through redistribution networks and food banks. **Recycle** consists of, as the name suggests, recycling FLW into animal feed and via composting. **Recovery** means treating unavoidable FLW and recovering energy (for instance, via anaerobic digestion). Finally, the least favourable option, **Disposal**, which means putting unavoidable FLW into landfills and not adding any value [66]. The authors from [66] built a diagram that shows what can be done to FLW, depending on variables like possibility of avoindance, edibility and fitness for human consumption while sorting all the FLW destination options in a descending order regarding favoritism (see Figure 13). As it can be observed in Figure 13, the most preferred options are **Prevention** and **Re-use**. On the other hand, the least preferred is always disposal. It is important to mention that the authors Papargyropoulou et al. (2014) consider that food surplus become waste from the moment it becomes inedible. Additionally, within category **Recycling**, the option **Animal feed** is the best one. In conclusion:

- If food surplus is being handled, the best option is always to prevent;
- If food waste is considered avoidable, and it is not possible to prevent, recycle it, preferably, by using it for animal feed purposes
- If unavoidable food waste is being handled, which is the worst scenario considered by the authors, it is better for the environment to recycle it, using it for animal feed purposes;
- Only disposal when there is no other option.

The authors from [58] developed a study where the objective was to choose the best available option to manage a spoiled beef stake contained in a plastic package (see Table 5).

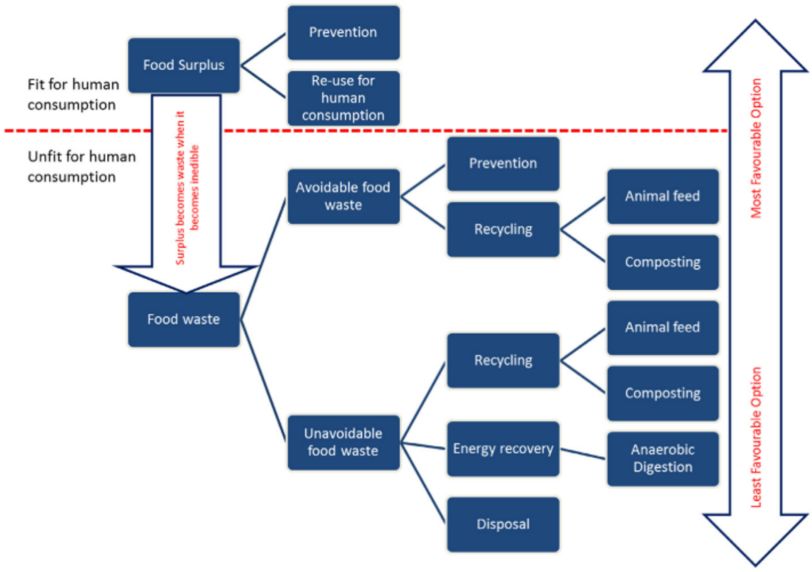


Figure 13 - FLW destination framework [66]

Table 5 - Best available options when dealing with a spoiled beef stake. Adapted from [58]

Criteria	Beef steak contained in a plastic package
Edibility	Edible
State	Spoiled
Origin	Animal-based
Complexity	Single product
Animal product presence	Meat
Stage of the FSC	Manufacturing
Treatment	Processed
Packaging	Packaged
Packaging biodegradability	Biodegradable
Best management option	1. Anaerobic digestion 2. Composting 3. Thermal treatment with energy recovery

As it was stated throughout the present section, the best way to avoid FLW is by preventing. Regarding the most efective ways to deal with the existent FLW along the FSC, many authors suggest preventive measures. Here is a list of the found articles that present the most effective ways of dealing with FWL: [40, 44-46] and [67-69].

3.2.5 Meat by-products recovery

The meat industry generates large volumes of by-products like blood, bones, meat trimmings, skin, fatty tissues, horns, hoofs, feet, skull and viscera among others that are costly to be treated and disposed ecologically. These costs can be balanced through innovation to generate value-added products that increase their profitability. The residuals contain proteins and other essential nutrients with potentially bioactive properties, eligible for recycling and upgrading for higher-value products, such as for human consumption, pet food and feed purposes and non-food and non-feed purposes [71]. However, the past crisis related to outbreaks of foot-and-mouth disease, the spread of transmissible spongiform encephalopathies (TSE), such as bovine spongiform encephalopathy (BSE) and the occurrence of dioxins in feeding stuffs, have shown the consequences of the improper use of certain animal-based products for public and animal health [72]. Since then, the European Commission published many regulations to prevent the reoccurrence of those crisis, which resulted in significative economic losses for the entire sector. Strict legislations regulate the utilization of various animal-based by-products and represent a major hurdle if not addressed properly [71]. This means that adequate disposal of by-products may increase the cost to processors and makes it necessary to produce new substances or products capable to cover the disposal costs [70].

In the meat industry, it is considered to be a by-product everything produced by or from the animal, except dressed meat. Animal by-products are divided into two classes: **edible** and **inedible**. Wholesale edible by-products are called **variety meats**. On the other hand, slaughter by-products, which include all of the animal that is not a part of the carcass, are often called **offal**. The offal, in turn, can be divided into **red offal** (head, liver, lungs, tongue, tail and so on) and **white offal** (fat) plus the set of guts and bladder, the set of tripe (rumen), the four feet and trimmings [83]. In addition, The English Food Standard Committee separates offal into two categories:

- **List A:** items from mammalian species that may be used in cooked or uncooked products. The list includes tissues such as diaphragm (skirt, cattle only), head meat (ox cheek, cattle only), and the heart, kidneys, liver, pancreas, tail meat, thymus and tongue. It also includes poultry parts such as the heart and liver. Originally, the list included the spinal cord and brain, but these are now banned for food due to the BSE outbreak.
- **List B:** items which may not be used in uncooked products This list includes mammalian parts such as blood, blood plasma, feet, large intestines, small intestines, lungs, esophagus meat, rectum, stomach (non-ruminant), first stomach (tripe, after cooking), second stomach (tripe, after cooking), fourth stomach, testicles and udder. It also includes poultry parts such as gizzards and necks [83].

Animal by-products arise mainly during the slaughter of animals for human consumption, during the production of products of animal origin, during the disposal of dead animals and during disease control measures. Regardless of their source, without any strict treatment, they threaten public and animal health, as well as the environment. Within the European Union, the Regulations 1069/2009 and 142/2011 impose health rules in order to control the risk by directing such products towards safe treatment methods. Animal by-products and derived products fall under this regulation if they are not intended for human consumption. Regarding the degree of risk involved, animal by-products are classified into three categories, where Category 1 refers to the material with the highest level of risk and category 3 with the lowest one [104,105]:

- **Category 1 (M1)** – high risk, being able to result in a human or animal fatal disease, without possibility of treatment. This category includes all the animal parts, including leather, skin, blood and hooves of animals suspected to being infected or having a transmissible disease; animals killed due to the eradication of transmissible diseases; body or body parts of pet, zoo and circus animals as well as animals used for experimental, scientific or wildlife purposes suspected of infectious agents; animal origin material that contains non-authorized substances residues, environmental contaminants or material collected in the process of waste water treatment; catering waste from boats and airplanes; and mixes of M2 and M3 by-products with M1 by-products (passes everything to M1). In general, this category includes cattle and small ruminants.
- **Category 2 (M2)** – agents' transmission capability, resulting in a danger disease, possible to be treated. This category includes slurry and digestive contents of slaughtered animals approved for consumption; animal material collected from effluents and slaughterhouses dealing with M2 products; animals that have veterinary drugs residues or imported animals not properly verified; animals or parts of animals which have not been slaughtered for consumption; and mixtures of category 2 with 3 (passes all to M2). In general, this category includes pigs, horses, rabbits and birds that have died accidentally or due to illness.
- **Category 3 (M3)** – negligible risk of diseases transmission (low risk). In this category, in general, are included parts of slaughtered animals that, for commercial reasons, are not for consumption; non-ruminants blood with the respective normal veterinary analysis; raw milk obtained from healthy animals (cow, sheep or goat); fish and other fishery products; shells, hatchery by-products and broken eggs; and blood, hides and skins, hooves, feathers, wool, horns and bristles of farmed animals.

In Figure 14, the most used processing methods and destinations for each meat by-products category can be observed.

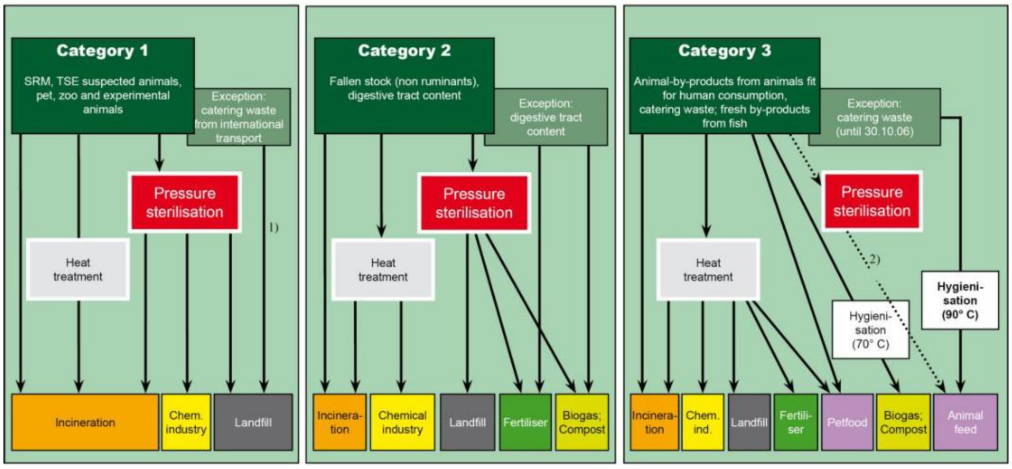


Figure 14 - The most used processing methods and destinations for each meat by-products category [104]

Considered highly valued delicacies or waste material away, the use and value of edible and inedible meat by-products depend entirely on the culture and country in question. In Table 6, some examples of traditional consumption of some edible meat by-products are presented. The fact that each the use of each by-product requires proper treatment such as collection, washing, trimming, chilling, packaging, cooling and so on must be highlighted. If not, such by-product cannot be properly valued or, worse, might harm consumers' health. Table 7 presents some potential uses and preparation of edible pig meat by-products.

If all animal by-products are considered, those can comprise a wide variety of products, including human or animal pet food or processed materials in animal feed, fertilizer or fuel [73]. The meat sector must use science and innovation to add value to animal by-products far beyond its profitability. It is necessary to analyze all animal by-products to search for key molecules that can be used in many fields like nutrition (bioactive peptides), food safety (antimicrobial peptides), medicine, cosmetics and so on, to develop new applications in order to add value to those by-products [73]. Despite all the possible benefits that the use of animal by-products can bring, it is often hard to implement them due to the existent difficulties to combine the use of innovative technology, processing methods, and adequate marketing of the product [73]. There are three main ways of adding value to meat by-products: they can be used in human food, for animal feed applications or for non-food and non-feed applications (see Figure 15) [70,74].

Table 6 - Examples of traditional consumption of edible by-products. Adapted from [73]

By-product	Traditional consumption	Countries
Liver	*Splinantero*	Greece, Turkey
	Sheep liver	Iran
	Paté	All Countries
	Meatballs	Portugal
Heart	Cooked and diced	South America
Testicles	*Criadillas*	Spain
Intestines	Casings for sausages	Mediterranean
Ears	Pork's ears	Mediterranean
Bones	Gelatin soups	Mediterranean
	Osso buco	Mediterranean
Tail	Bull's tail	Mediterranean
	Tail pork	Mediterranean

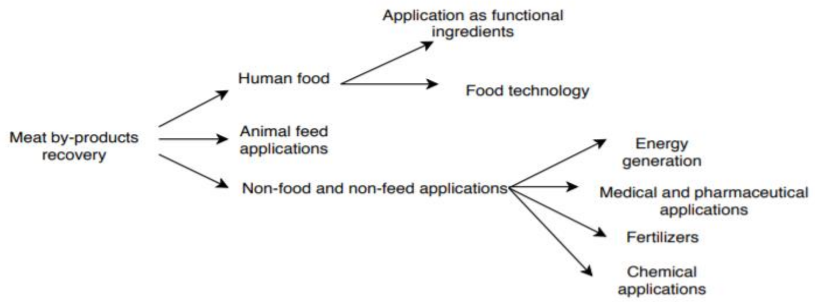


Figure 15 - Possible ways of recovering meat by-products

Table 7 - Potential uses and preparation of edible pig meat by-products. Adapted from [83]

By-products	Storage and preparation	Way in which it is used
Liver	Frozen, fresh or refrigerated	Braised, broiled, fried, in loaf, patty and sausage
Kidney	Whole, sliced or ground. Fresh or refrigerated	Broiled, cooked in liquid, braised, in soup, grilled, in stew
Heart	Whole or sliced. Frozen, fresh or refrigerated	Braised, cooked in liquid Luncheon meat, patty, loaf
Brains	Whole, sliced	Sausage ingredient. Broiled, braised and cooked in liquid, poached, scrambled
Tongue	Frozen, fresh or refrigerated. Whole	Cooked in liquid, cured, sausage ingredient, salad, jelly
Stomach	Fresh, refrigerated, smoked and pickled	Broiled and cooked in liquid, sausage casing, sausage ingredient
Spleen	Fresh, refrigerated and precooked	Fried, in pies, in blood sausage
Tail	Frozen, fresh, refrigerated	Cooked in salty liquid
Intestines (small and large)	Whole. Frozen, fresh, refrigerated. Remove faeces. Soak, wash, salt before use	Sausage casing
Cheek and head trimmings	Frozen, fresh, refrigerated	Cooked sausage
Ear	Frozen, fresh, refrigerated	Smoked and salted, stewed with feet
Skin	Fresh, refrigerated	Gelatine
Feet	Frozen, fresh, refrigerated	Jelly, pickled, cooked in liquid. Boiled, fried
Fat	Frozen, fresh, refrigerated	Shortening, lard Blood
Blood	Frozen, refrigerated	Black pudding, sausage, blood and barley loaf
Bone	Frozen, fresh, refrigerated	Gelatine, soup, jellied products, rendered shortening, mechanically deboned tissue
Lung	Frozen, fresh, refrigerated	Blood preparations, pet food

Firstly, meat by-products can be used as **functional ingredients**. The influence of the methods and of their operating conditions on the extraction, purification and concentration of meat proteins (beef, pork lungs and chicken meat) has been investigated in order to maximize protein recovery and to enhance protein functional properties for subsequent application as food ingredients [74]. The use of by-products as a source of bioactive peptides has been extensively studied during the last years. In this line, blood and collagen, very important by-products from slaughterhouses and meat industry, have been the most studied and tested ones. Blood is a rich source of proteins where hemoglobin, an iron-containing protein, is the most abundant complex. It is obtained all around the world and, even though it is used as food ingredient in Europe, Asia, and Africa, its production is more abundant than needed. Its value as a source of bioactive peptides has been studied in both the cellular fraction (hemoglobin cells) and the plasma fraction, and their hydrolysates have been described to exert antimicrobial, antioxidant, ACE-inhibitory (Angiotensin-converting-enzyme), and opioid activities [70]. In addition, animal by-products hold a considerable potential for preparation of protein hydrolysates that was rich in some of the essential amino acids. The hydrolysates may be used as flavor enhancers, functional ingredients or as nutritional additives to foods of low protein quality [74].

Secondly, meat by-products can be useful to enhance **food technology**. The cellular fraction that contains red blood cells, white blood cells and platelets can be used as a color enhancer for sausages, even though it has limited applications in foods due to the dark color of hemoglobin, sensory adverse effects or even hygiene. Better flavor can be obtained if hemoglobin is removed and used to replace fat in meat products. Blood proteins can contribute to gelation and emulsification, proteins enrichment for food with low levels of proteins and even to foaming. High antioxidant activity has been reported in red blood cell fractions from sheep, pig, cattle and red deer. The enzyme thrombin and fibrinogen are used for binding of meat pieces and, for instance, reconstitute meat steaks or generate meat emulsions increasing the hardness and springiness. Pig slaughter result in a low amount of residuals because large parts of the skin and fat contains substantial amounts of easily solubilized collagen that are used as a binding-ingredient in sausages and other mixed products [71]. Gelatin is obtained from collagen through hydrolysis and is widely used in the food industry because of its good gel-forming ability, but also as clarifying agent, stabilizer or protective coating material [70].

Thirdly, meat by-products can be used in **animal feed applications**. About 15 million tons of animal by-products in the European Union are processed per year by rendering to produce high quality fats and proteins in order to be used as ingredients in feeds and pet foods. Meat by-products protein hydrolysates represent an interesting alternative to soybean meal because of the absence of antinutritional factors or allergenic proteins and the presence of large amounts of all essential amino acids. In fact, animal by-products constitute a good source of nutrients like essential amino acids, fatty acids, minerals and trace elements, B vitamins and some fat-soluble vitamins. Meat and bone meals are also a good source of essential amino acids and group B vitamins for animal feeds [70].

Recently, animal by-products have been used in for **energy generation**. In recent years, biodiesel has been produced and is now replacing progressively the diesel fuel due to its advantages, like being biodegradable, non-toxic and with a favorable combustion emission profile that leads to reductions in carbon dioxide, carbon monoxide, particulate matter and unburned hydrocarbons. Additionally, the use of biodiesel does not imply significant modifications in engines. Other recent studies focus on the improved production of biodiesel by using ultrasounds assisted transesterification of the animal fats. However, animal fats have some limitations due to its protein and phosphoacylglycerols content that makes a degumming process necessary, the presence of water that requires of vacuum drying and the high content of saturated fatty acids that need to be reduced through winterization process or additives addition. The developments have continued and nowadays a new second generation, so-called biogas oil is facing prompt application [70].

Additionally, meat by-products can be utilized for **medical and pharmaceutical** needs. Pork skin can be used as dressing for burns or skin ulcers in humans. Glands and organs constitute edible meat by-products with good nutritive value that are consumed in different regions of the world and, in fact, some of them are consumed for medicinal purposes in countries like China, Japan and India, or used as a source of pharmaceutical substances. Low molecular weight ultrafiltrates obtained from pig aorta extracts were assayed with laboratory guinea pigs and such extracts were reported to exert substantial reductions in atherogenic lipoproteins, atherogenic index and total and residual cholesterol [70].

Moreover, animal by-products can be useful for **fertilization**. Large amounts of meat and bone meal are generated in all countries and an interesting approach is the thermochemical processing including pyrolysis, combustion and gasification. The resulting ashes demonstrate a high content of phosphorus which makes them suitable as fertilizers and the gas emissions are within the international regulations and contains combustibles to be used for energy production. The incineration of animal by-products results in good mineral fertilizers [70].

Finally, meat by-products can be used for **chemical purposes**. Rendered fats have many applications in cosmetic industry for products like hand and body lotions, creams and bath products. Fatty acids are used in the chemical industry for rubber and plastic polymerization, softeners, lubricants and plasticizers. Collagen, gelatin and glycerin are also used in chemical industry as ingredients for surfactants, paints, varnishes, adhesives, antifreeze, cleaners and polishes. Polymers taken from animal fat have the advantage of being biodegradable and constitute an attractive alternative to plastics produced from petroleum. There are also many applications for hides, which include leather-based articles like clothes, shoes, belts, handbags and purses [70].

Additionally, Table 8 is presented so that the most common uses some animal by-products can be displayed in an organized way.

Table 8 – Common uses of animal by-products. Adapted from [82]

Animal by-product	Reprocessed Products	Major uses
Hides and skin	• Cured hides and skin. • Leather and textiles	Leather clothes, belts, car and household upholsteries, bags, footwear, drums, luggage, wallets, sports goods, gelatine and so on.
Hoof and horns	• Hoof and horn meal • Gelatine and keratine extraction	Combs, buttons, plates, souvenirs. Fertilizer, collagen, glue, gelled food products, foaming in fire extinguishers.
Bone	• Extraction of collagen • Bone meal	Cutlery handles, shortening, bone gelatine, bone meal, Collagen
Blood	• Pharmaceutical products • Blood meal	Catgut, tennis strips, blood sausages or pudding, fertilisers, animal feeds, emulsifier and stabilizer
Intestine	• Sausage casing • Surgical sutures • Musical instruments	Sports guts, musical strings, prosthetic materials, collagen sheets, burn dressing, strings for musical instruments, sausage casings, human food, pet food, meat meal, tallow, casings Pharmaceuticals
Organs and Glands	• Pharmaceutical • Medicinal • Xenotransplantion	Heart stimulant, heparin, corticotrophins, enzymes, steroids, oestrogen, progesterone, insulin, trypsin, parathyroid hormone Xenotransplantation
Hair/Wool	• Textiles • Extraction of keratin	Clothes or woven fabrics, mattress, keratin, carpets, knitted apparels, insulators

3.3 Collaboration

Previous studies indicate that FLW occur throughout the entire FSC. This means that there is no specific stage of the FSC to be blamed. Additionally, because, as it was discussed in section 3.2.3, there are different causes for FLW for different FSC stages, meaning that there is no single solution to solve the problem. Hence, communication and collaboration between all FSC stakeholders is crucial so that FLW can be reduced [75]. Collaboration consists of two or more companies working together to create competitive advantage and higher profits that cannot be achieved by any of those companies alone. This relationship is characterized by the sharing of risks, cost and rewards by the companies involved [76]. It is known as a fact that collaboration brings numerous benefits, such as improved efficiency and performance due to capitalization on resources, capabilities, processes and routines. In addition, the rapid technology development and globalization make inter-organizational relationships almost inevitable, as they seek productive efficiencies in sourcing, production, distribution, retail and in all other supply chain stages. Moreover, uncertainties in consumer demand also enhances the need for collaboration [76]. However, collaboration can bring several problems due to the investments and organizational changes needed, the potential increase of dependence, and complexity to manage extra relationships [78]. There are three types of collaboration [76]:

- **Vertical collaboration,** where two or more entities from the same supply chain share their responsibilities, resources, risks and information to serve similar end customers. In the agri-food industry, this type of collaboration usually occurs between manufacturer-supplier and grower-processor.
- **Horizontal collaboration,** where two or more distinct (sometimes competing) entities cooperate by sharing information and resources in order to better serve customers. In the agri-food industry, this often occurs in transportation management and sometimes producers.
- **Lateral collaboration,** where actions from vertical and horizontal collaborations are combined in order to maximize flexibility and share of capabilities.

The implementation of a sustainable development in a supply chain brings many advantages, such as reduction of business waste, reduction of environmental impact, increased market performance (access to new markets and competitive advantage), better corporate image performance, increased financial performance (increased margins, market share and power), better manufacturing performance (in terms of energy efficiency, materials and innovation) and lower FSC costs [77]. The International Institute for Sustainable Development stated, in 1992, seven steps that need followed in order implement a sustainable strategy among supply chain partners (see Table 9) [79].

Table 9 - Steps for implementing sustainable collaboration. Adapted to [79]

Steps	Description
1. Stakeholders' analysis	Identify all entities direct and indirectly involved in the company activities. The complexity and heterogeneity related with the relationship between the various stakeholders can make this analysis difficult.
2. Objectives and policies	Articulate and share companies' values regarding sustainable development, defining operational performance goals
3. Implementation plan	Implement general sustainable development policies into operations. It may involve changing corporate behaviours.
4. Support corporate policy	Through efficient communication and active participation of all collaborators in searching and ideas executing processes.
5. Measures and performance criteria	Collection of sharable information in order to compare internal and external performance indicators, involving adapting information systems.
6. Reports	Write reports that summarize the collection and evaluation of information, which will then be shared with all interested parties involved
7. Monitorization	Check the development. It involves the implementation of meetings involving all stakeholders in order to optimize processes.

Unfortunately, no research papers regarding by-products recovery through FSC collaboration were found. Nevertheless, many publications describe collaborative initiatives to recover food waste. Besides the initiative developed by FoodDrink Europe that was presented in section 3.1.3, one quite interesting initiative is the one called Last Minute Market (LMM), which was originated at the Faculty of Agriculture of the University of Bologna in 1999 and still exists until this day. Its purpose is to reduce and recover FLW, that otherwise would be discarded, and transform it into a useful resource. Later in 2010, the LMM started acting at a European Level through numerous campaigns, such as: i) the awareness campaign "A Year against Food Waste", ii) the Joint Declaration against Food Waste (2010), iii) the European Resolution against Food Waste (2012), iv) the Charter for a Zero Waste North East and Euroregion (2012) and v) the release of publications and scientific articles (Black Book on Food Waste, Blue Book on Water Waste, Transforming Food Waste into a Resource and so on) [80].

Another relevant action was the public initiative that was developed in Denmark in 2011, when the Danish Ministry of the Environment established a voluntary ''Initiative Group Against Food Waste'' where stakeholders representing the public and private sectors worked together in order to reduce FLW in the Danish food system. From these meetings the ''Charter on Less Food Waste'' was created and signed by 19 major stakeholders, including supermarket chains, restaurants, ministries, and hotel chains [81].

3.4 VRP for waste collection

As previously stated, the main objective of the present dissertation is to find solutions that add value to meat products that otherwise would be wasted, while knowing that those same solutions must be economically, environmentally, and socially sustainable. To do so, optimization techniques must be applied, so that the values of the most important KPIs related to sustainability can be obtained. Such KPIs include cost of travelling, fuel consumption, CO_2 emission levels and many others. This type of methods is crucial when applied in the context of this dissertation, especially in the phase of collecting by-products from numerous slaughterhouses. With that in mind, the present section has as main goal to give some insights regarding the most important concepts related to optimization models and, more specifically, related to VRP (Vehicle Routing Problem) models and even waste collection problems, which is highly relatable to the context of the present work.

3.4.1 The Vehicle Routing Problem (VRP)

The main goal when solving a VRP is to find the set of routes that satisfy the imposed constraints and minimize the total cost of travelling. In the last decades, the VRP has been playing a very important role in the context of planning of distribution systems and logistics in many sectors [87,88]. The sector which the present work will be more focused on is the waste collection.

In a classical VRP, the customers, as well as their respective locations, are previously known. The driving time between the customers and the service times at each customer are also often known. When presenting a VRP, the customers' locations are described within a graph composed by vertices (which represent the point where each customer is located) and a set of arcs. Each arc (i, j), where i is always different than j, is always linked with a distance, or, in some cases, with a travelling cost or traveling time. Moreover, it is assumed that there are a certain number of vehicles available, being that number represented by a fixed constant, or a range of constants (with a minimum and a maximum number of available vehicles). Sometimes, mainly in the cases where the number of available vehicles is not fixed or limited, a cost of using a vehicle is imposed in the model. Most importantly, when solving a VRP, one must keep in mind that: each customer is visited exactly once, by exactly one vehicle; all vehicle routes start and end at the depot; all other constrains imposed in the mathematical model must be satisfied [87].

The problems to be solved in the practical real life are often more complicated than the one presented by the Classical VRP. Therefore, many subtypes of VRPs were created over the last years in order to better translate the complexity of logistics and distribution systems [88]. The most important VRP subtypes are the following ones:

- **VRP with Time Windows** – it is a combined vehicle routing and scheduling problem that optimizes the use of a fleet of vehicles that must make a number of stops to serve a set of customers, and to specify which customers should be served by each vehicle and in what order to minimize the cost, subject to vehicle capacity and service time restrictions [87].

- **VRP with Pick-up and Delivery** – it is also often called VRP with Backhauls. This type of VRP considers the fact that, in real life, goods not only need to be taken from the depot to the customers, but also must be picked up at several customers and taken back to the depot [87].
- **Capacitated VRP** – The reasoning behind this particular type of VRP is very similar to the one of the Classical VRP. The main difference is that in the Capacitated VRP, the capacity of each vehicle (which can be translated in terms of weight or volume) is presented in the mathematical formulation of the problem [87].

Over the years, many known authors used several algorithms in order to solve VRP problems. Such algorithms include the use of Tabu Search, Genetic Algorithms, the Ant Colony optimization and so on [88].

3.4.2 Waste Collection

The theme “waste collection” is highly related to the theme of the present dissertation. This is because most waste collection papers study the most efficient way of collecting waste throughout a city or a region in order to later add value to that same waste that was collected. When comparing this idea with the main goal of the present work, one understands that they are quite similar.

The concept of smart city is enabling modern opportunities for handling waste management practices. The existing studies have started addressing waste management problems in smart cities mainly by focusing on optimizing the routes for waste collection vehicles. The aim of this optimization is to minimize operational costs, energy consumption and transportation pollution emissions [89,90].

Concerns regarding the efficiency of managing waste have rapidly increased with the emerging modern era. With that in mind, many municipalities were forced to assess the cost-effectiveness and environmental impacts of their waste management systems, especially when designing waste collection route [90]. Among all steps of waste management (which include source-separation, storage, collection, transfer and transport, processing and recovery, and disposal), the collection phase is considered the most critical one [89].

Researchers from all over the world have already conducted several studies on monitoring different steps of the waste collection process by applying modern technologies, which involve the idea of smart bins that monitor their waste status and are able to transmit that same status to a depot through a modern information system [89]. The idea is to create a waste collection route that is more efficient by only emptying the full smart bins, based on the real-time waste statuses of those same smart bins. Nevertheless, it is important to comprehend that the routing problem is computationally quite challenging, and, in the case of large systems, it is impossible to apply optimal exact methods. Therefore, comparatively new algorithmic approaches, such as heuristic and meta-heuristic, are often applied in those cases in order to obtain the most optimized result [90].

In this dissertation, the waste collection problem will be designed as a Capacitated VRP (described in section 3.4.3), as has been applied in several other studies, which enables the design of an effective collection route.

3.4.3 Capacitated VRP applied to waste collection

The general Capacitated VRP (CVRP) model applied to waste collection is explained in this section in accordance to the nomenclature and formulation presented by the paper stated in reference [89]. Before going any further, it is important to mention that the mathematical model that will be demonstrated is merely based on the most generic CVRP model, meaning that only the indispensable constraints will be stated and that several other constraints can and may be added to the model that follows if they better represent the specific situation under study.

First, there are n bins and k vehicles to be considered in this model. There is a graph G = (V, E), where V = {0,1,…,n} is a vertex (bin) set and E is the arc set. In this case, 0 represents the depot. The other vertices (i=1,2,…,n) represent the bins that must be visited by a truck. Each bin contains a certain quantity of waste, c_i. A set of vehicles k = {1,…,K} is initially stationed at the depot. Each truck has a capacity of C. There is a cost associated with the transportation between each arc (i,j), d_{ij}, where i is always different than j. Then, q_{ijk} represents the load of vehicle k while traversing arc (i,j). Finally, the absolute distance between two nodes is represented by $dist_{ij}$.

In order to achieve the objective of minimizing total costs under more realistic circumstances, there are some general constraints that are often imposed in CVRP models. Firstly, all vehicles start from and return to the depot. The depot also acts as a waste transfer facility. All vehicles start their routes at the same time. Each waste bin is visited by only one vehicle during each collection time. The waste accumulated by each truck during a route must not exceed the capacity of that same truck. The fleet of all vehicles are homogeneous and traffic congestion is neglected during the entire waste collection process [89].

The typical CVRP model starts by clustering the most prioritized bins, which are the ones whose waste level surpasses a predefined threshold waste level. After this prioritization process, the route optimization is performed considering the chosen cluster. The mathematical formulation is presented as follows. First, the decision variable is defined by equation (1) in the following way:

$$X_{ijk} = \begin{cases} 1, if\ vehicle\ k\ goes\ through\ arc\ (i,j) \\ 0, otherwise \end{cases} \quad (1)$$

The objective function is described by equation (3), whose main goal is to minimize total travelling costs.

$$Min\ \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{K} d_{ij} X_{ijk} \quad (2)$$

Subject to:

$$\sum_{j=1}^{n} X_{0jk} = 1 \quad \forall k = 1,2, \dots K \quad (3)$$

$$\sum_{j=1}^{n} q_{0jk} = 0 \quad \forall k = 1,2, \dots K \quad (4)$$

$$\sum_{i=0}^{n} \sum_{k=1}^{K} X_{ijk} = 1 \quad \forall j = 1,2, \dots n \quad (5)$$

$$\sum_{j=1}^{n} X_{ijk} = \sum_{j=1}^{n} X_{jik} \quad \forall i = 0,1,2, \dots n; \quad k = 1,2, \dots K \quad (6)$$

$$\sum_{i=0}^{n} \sum_{k=1}^{K} q_{jik} - \sum_{i=0}^{n} \sum_{k=1}^{K} q_{ijk} = c_j \quad \forall j = 1,2, \dots n \quad (7)$$

$$\sum_{i=1}^{n} c_i X_{ijk} \leq C \quad \forall k = 1,2, \dots K \quad (8)$$

$$\sum_{i=1}^{n} X_{i0k} = 1 \quad \forall k = 1,2, \dots K \quad (9)$$

The first two constraints, presented by equations (3) and (4), specify that vehicle k starts the tour at the depot, empty. According to equation (5), each bin is visited by exactly only one truck. Then, equation (6) ensures the continuity condition, meaning that, if vehicle k enters a node (bin), it must also leave that same node. Equation (7) ensures that each vehicle empties the bins it visits along its route. Then, equation (8) shows that the total collected waste from all the bins visited by each vehicle must not exceed the capacity of the vehicle. Finally, after the last bin of the tour, the vehicle returns to the depot according to equation (9) [89].

3.5 Chapter conclusions

This literature review allowed us to understand how, considering the fast-growing population and consequent increase of food demand, it is impossible to feed everyone on earth by just increasing food production, due to the existent limited available resources. Therefore, it is crucial to promote sustainable development. In that sense, many international sustainable initiatives were displayed in this chapter. Unfortunately, as it was explained in this chapter, it is not so easy for FSC entities to collaborate neither to capitalize on FLW due to strict food legislation that is implemented in the EU, especially in the meat sector, due to past crisis related to outbreaks. Food companies must be always aware of product quality standards, food safety, labelling, materials in contact with food and so on.

Additionally, it was also studied in this section one of the clearest signs of unsustainability among FSCs is studied: the food loss and waste. It is explained how FLW affects society, the environment and the economy. In that sense, the most commonly used FLW destinations are also presented, from the least to the most preferred ones. Finally, as it is one of the most important issues that are currently approached by the *MobFood* Project, it is studied how meat by-products can have multiple purposes: functional ingredients, food technology, energy generation, medical and pharmaceutical applications, fertilization and chemical applications.

As stated before, collaboration is a key factor when aiming for sustainability along any FSC. With that in mind, advantages and risks of collaboration are studied. Also, the steps for implementing sustainable collaboration among agri-food interested stakeholders are herein presented.

In the last section, because it is crucial to try to minimize costs when achieving any goal related towards sustainability, concepts related to optimization models are analyzed. Because one of the specific problems under study in the context of the present dissertation is the collection of by-products, VRPs and, more specifically, waste collection problems are also studied in this section. To better demonstrate how a waste collection problem is usually approached by researchers who seek to solve such problems, a mathematical formulation that aims to minimize total travelling costs while respecting several realistic constraints is demonstrated.

4. Methodology

So far, many ideas on how to value unused edible pig meat by-products were suggested throughout the previous chapter. However, from this point on, a single idea proposed by the author will be studied. Such idea consists of the export of edible pig meat by-products to China. The purpose of the present and following chapters will be to test this idea by balancing all costs involved with the benefits that all stakeholders, herein companies and citizens involved, may get from it.

The entire process can be divided into two main phases: **the collection and storage phase**, which refers to how by-products are collected and treated in national territory; and **the export phase**, referring to the transport and arrival of such by-products to China. The first part of the present chapter will present the first phase. It consists of the collection of pig meat by-products from multiple slaughterhouses located in Lisbon and Tagus Valley, as well as in the central region of mainland Portugal. The problem enclosed in this first phase can be formulated as a VRP (Vehicle Routing Problem) and it is intended to be solved through the optimization of a mathematical model. The goal is to determine the best set of pairs trajectory-trucks which return the minimum collection cost. Then, the by-products will be stored until they are ready to be exported, which leads us to the second phase.

The second part of the chapter will present the second phase of the problem. Firstly, the main features that make the Chinese pig meat market such a promising opportunity to be explored when it comes to the export of pig meat by-products will be presented. Then, the most critical challenges when it comes to choosing the best way of exporting meat by-products will be presented. Many topics must be discussed, such as the way of transportation (air freight or ocean/sea freight), the incoterm to be established, and much more. The main purpose of this analysis is to provide a framework that helps a potential exporter to decide which is the best way of transportation, considering factors such as the required speed of transportation, the demand and the cost that the exporting company is willing to support.

To summarize, the main objective of this chapter is to present a methodology that explains how all the costs will be considered and later computed, while stating the necessary conditions for all the processes stated above to be put into practice. The chapter's scheme is presented in Figure 16.

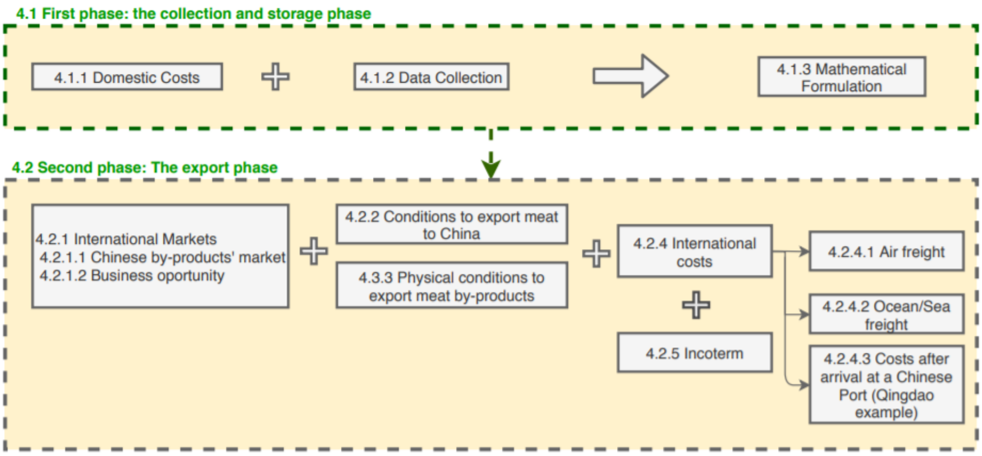


Figure 16 - Methodology's scheme

4.1 The first phase: the collection and storage of by-products

The process suggested by the author begins with the collection of large quantities of pork by-products, performed by a company specialized in meat products logistics. The entity which was used as a reference for the collection process was Abapor (see section 2.3.1). As it was stated in that same section, Abapor's consists on the collection of meat by-products from the modern distribution, municipal markets and industries. For this dissertation, it was assumed that Abapor is also capable of collecting by-products from slaughterhouses as well. In addition, as it was also stated in section 2.3.1, the ETSA Group operates under four collection points. For purpose of this dissertation, only one collection point was considered to aggregate and store all by-products after they are collected from multiple vehicles: the one located in Loures. This is because of three main reasons. First, that collection point is very close to the port and airport of Lisbon. Secondly, the two Portuguese regions that contain the highest number of slaughterhouses are near Loures (the Lisbon/Tagus Valley region and the central region of mainland Portugal). Finally, the collection point is specialized in the collection, sorting and processing of M3 meat products (see the definition of M3 products in section 3.2.5).

The Portuguese regions that are being considered for the collection process are the Lisbon and Tagus Valley region and the central region of mainland Portugal. The main goal will be for the logistics company to collect all the by-products from the slaughterhouses by using specialized trucks while minimizing the total travelling costs. The collection frequency will be every three working days, that is, the same as the one the one that is performed by Abapor, according to reference [106]. As the collection is performed every three working days, it is considered that the by-products, while they are in the slaughterhouse (that is, before they are collected), are stored between one and three days, depending on when they are extracted from the pig. After they are collected, that is, when all the collected by-products are aggregated in the collection point that is located in Loures, it is considered that these can be stored between two and seven days (this idea will be better explained in section 5.2.2).

After all the assumptions are considered and the data is collected, a VRP is being solved by formulating a MILP (Mixed Integer Linear Programming) model to find the best set of trajectory-trucks that find the minimum cost. With that in mind, all the necessary steps that the author needed to put into practice in order to solve the VRP will be stated throughout section 4.1. Firstly, this section starts with the statement of all costs incurred in the collection and storage of the collected by-products. Then, an explanation regarding how all the necessary data (distances, capacities, costs and so on) was gathered by the author is demonstrated. Finally, the mathematical model that allowed the VRP to be solved is shown and explained.

4.1.1 Domestic costs

In the context of this work, domestic costs represent all the costs incurred in the process of collecting from the desired slaughterhouses and storing them. All considered costs are represented in Table 10 and will be used in the model presented in section 4.1.3. One must note that the costs herein presented are a simplification of reality. In the context of this dissertation, the author decided to assume that the collected products are not purchased from the companies that own the slaughterhouses. Therefore, the entire collection process represents an act of collaboration between several companies, including Abapor. Hence, it was admitted that, if there are no purchasing costs, the profit resulting from the final sale of all by-products will be distributed according to the costs incurred by each company involved.

Table 10 - Domestic costs

Name	Description
Salaries	The sum of all workers' wages who drive the trucks so that the by-products can be collected.
Tolls	Charges payable to drive on bridges or certain roads.
Fuel costs	Total fuel expenditure to travel the necessary distances in order to collect by-products from all collection points.
Warehousing costs[1]	They are referred to the total cost of holding inventory. Inventory costs usually include costs such as rent, utilities, salaries, opportunity costs, and costs related to perishability, shrinkage, and insurance.

[1]This cost was not used in the mathematical formulation presented in section 4.1.3 but it will surely be considered when calculating the final cost of exporting the collected by-products. Such cost will be calculated according to Greenyard's storage costing model (see section 5.2.2).

4.1.2 Data collection

Considering the location of Abapor's collection point being considered in the present dissertation, the author considered the slaughterhouses, dealing with pig and piglet meat, located in the areas of Lisbon, Tagus Valley and in centre of mainland Portugal (see Annex 1). So that the locations of such slaughterhouses could be obtained, the author resorted to DGAV's website (General Directorate of Food and Veterinary) [107]. On the website, all addresses are available, as well as the activities each slaughterhouse practices and the type of cattle that each one slaughters. It is worth mentioning that 50 slaughterhouses are being considered in the context of this work (20 located in Lisbon and Tagus Valley and 30 in the centre of mainland Portugal). From those slaughterhouses, 26 have a meat processing centre integrated.

In order to obtain the distances between the slaughterhouses (see Annex 2), the author used Google Maps, where the slaughterhouses' addresses were used as inputs [100]. In the context of this work, it was considered that the travelled distance between point A and point B was the same as the one between B and A. Then, to obtain the value of each toll (see Annex 3), the same addresses were used in the Michelin's website, using the same inputs [102]. An example can be observed in Figure 17. In the case of Figure 17, the locations of *Tricar* and *Mercarne,* which are two slaughterhouses that were considered in the implemented mathematical model, were used as inputs in Google Maps in order to obtain the distance between them (look at the image on right, in Figure 17). Then, the addresses of the two same slaughterhouses were used as inputs in the Michellin's website in order to obtain the value of the toll that must be paid in order to travel between those two slaughterhouses (look at the image on the left, in Figure 17). By applying the same method to all the slaughterhouses under study, it is possible to create a matrix containing the distances between all the slaughterhouses and another one containing all the tolls that one must pay when travelling between the slaughterhouses.

The methodology applied in order to get the quantity of generated by-products per working day by every slaughterhouse was more complex. Unfortunately, there is no way to get direct information regarding the quantity of by-products generated by each slaughterhouse by visiting websites or articles. Therefore, the author had to find a way of obtaining a reasonable approximation regarding the quantity of by-products generated by each slaughterhouse. All information was collected from reference [111], a report that has all the data related with cattle that was slaughtered in 2013, in Portugal. Table 11 contains information regarding the number of classified slaughtered pigs in the centre, Lisbon and Tagus Valley.

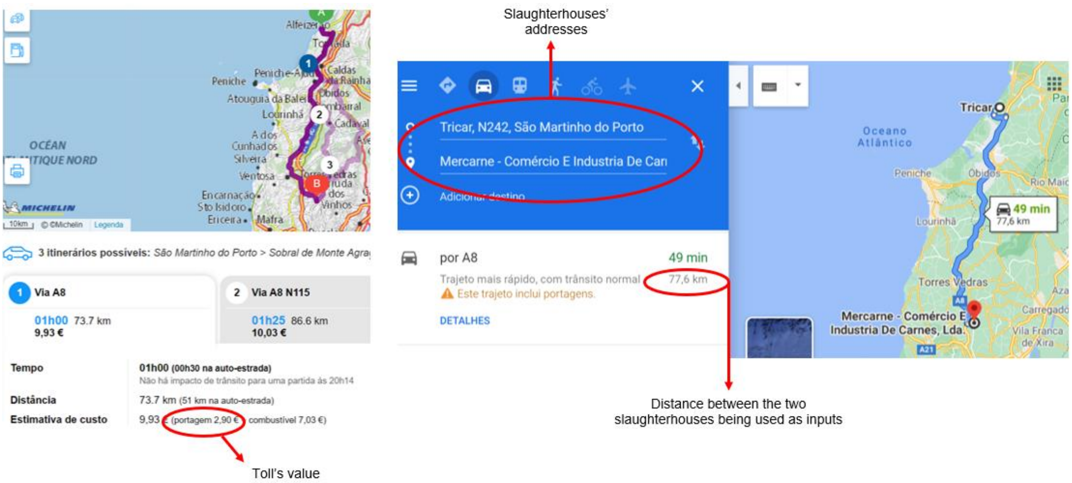


Figure 17 – Travelled distance (image on the right, taken from Google Maps) and paid toll between two slaughterhouses (image on the left, taken from Michelin's website). In this case, between Tricar and Mercarne [100,102]

In this document, the slaughtered pigs are classified according to their lean meat percentage. Lean meat refers to meat that contains low levels of fat. If the value for a given pig is equal or greater than 60%, it is P; if it is equal or greater than 55% and lower than 60%, it is E; if it is equal or greater than 50% and lower than 55%, it is U; if it is equal or greater than 45% and lower than 50%, it is R; if it is equal or greater than 40% and lower than 45%, it is O; if it is lower than 40%, it is E [112]. Because the author had no information regarding the classes allowed in each slaughterhouse under study, all classes were considered. At this point, it is known that there were 425 825 and 2 097 498 slaughtered pigs in the Centre and Lisbon/Tagus Valley, respectively, in the year reported in the document. Then, as the author also had no information regarding the weight of all pigs that were slaughtered in each slaughterhouse in 2013, a calculation was made in order to obtain the average weight of the slaughtered pigs. Table 12 contains information regarding the number of slaughtered pigs throughout Portugal weighing less than 20 kilograms, between 20 and 50 kilograms and more than 50 kilograms.

Table 11 - Classified pig slaughters

Classification	S	E	U	R	O	P	Total
Centre	170628	206672	41969	5642	532	382	425825
Lisbon and Tagus Valley	616533	1165379	282491	28718	3267	1110	2097498

Table 12 - Number of slaughtered pigs, according to their weight, in 2013

Pigs ≤20 Kgs (piglets)	Pigs >20kgs and <50 Kgs	Pigs ≥50 Kgs (fattening pigs)
658 000	468 000	659 000

In order to calculate the average weight of a slaughtered pig, the author assumed that the weight of an average piglet was 20 Kgs, that the weight of a regular pig was 35 Kgs and that the weight of an average fattening pig was 70 Kgs. By using equation (10), the average weight of a pig was obtained.

$$Weight\ of\ an\ average\ size\ pig = \frac{35*468\,000+70*659\,000}{468\,000+659\,000} \cong 55.47\ Kgs \qquad (10)$$

As it can be observed in equation (10), the weight of an average-sized pig was obtained through the multiplication of the numbers which correspond to the pigs weighing between 20 and 50 Kgs and the fattening pigs, presented in Table 12, with their respective attributed weight (stated in the last paragraph), divided by the total number of regular pigs and fattening pigs.

Regarding the slaughterhouses located in the Centre and in Lisbon/Tagus Valley, some of them deal exclusively with piglets, others exclusively with average sized pigs and others with both piglets and average sized pigs. There were exactly 25 (5 in Lisbon and Tagus Valley and 20 in the Centre) slaughterhouses dealing exclusively with piglets, 16 (12 in Lisbon and Tagus Valley and 4 in the Centre) exclusively dealing with average sized pigs and 9 (3 in Lisbon and Tagus Valley and 6 in the Centre) dealing with both. Regarding the slaughterhouses which deal with both piglets and average sized pigs, the author had to calculate the portion of each of those slaughterhouses that actually deals with piglets as well as the portion that deals with average sized pigs. To do so, the author calculated the portion of piglets that were slaughtered across Portugal in 2013 and used that value as a reference to estimate the portion of the slaughterhouse that deals with piglets and average sized pigs (observe equation (11), whose values were taken from Table 12)

So, really, there are 5+(0,3686*3) piglet slaughterhouses and 12+((1-0,3686)*3) average sized pig slaughterhouses in Lisbon and Tagus Valley; and 20+(0,3686*6) piglet slaughterhouses and 4+((1-0,3686)*6) average sized slaughterhouses in the Centre of mainland Portugal. The portion of the total number of slaughtered pigs that refers to piglets is given by equation (11).

$$Portion\ of\ produced\ piglets\ in\ Portugal = \frac{658\,000}{658\,000+468\,000+659\,000} \cong 0.3686 \qquad (11)$$

As it can be observed in equation (11) the portion of produced piglets in Portugal is given by the quotient between the number of piglets in Portugal (observe Table 12) and the sum of the existent pigs in Portugal, presented in the same Table. With that in mind, Table 13 presents the total quantity of produced piglet meat and average sized pig meat in each of the studied zones in a working day.

Table 13 - Total quantity (Kgs) of produced piglet meat and average sized pig meat in a slaughterhouse, in each of the studied zones, in a working day

Zone	Piglets	Average sized pigs
Lisbon and Tagus Valley	$\frac{2\,097\,498 \ * 0.3686 * 20}{(5 + 0{,}3686 * 3) * 253^{1}} \quad (12)$	$\frac{2\,097\,498 \ * (1 - 0.3686) * 55.47}{(12 + (1 - 0{,}3686) * 3) * 253^{1}} \quad (13)$
	Result = 10 009.763	Result = 20 898.265
Centre	$\frac{425\,825 \ * 0.3686 * 20}{(20 + 0{,}3686 * 6) * 253^{1}} \quad (14)$	$\frac{425\,825 \ * (1 - 0.3686) * 55.47}{(4 + (1 - 0{,}3686) * 6) * 253^{1}} \quad (15)$
	Result = 558.620	Result = 7 568.767

[1]The year of 2020 has exactly 253 working days

For each zone, there are three options regarding the dairy volume of pig meat with which each slaughterhouse can operate:

- A slaughterhouse can deal exclusively with piglets, meaning that that the quantity of generated pig meat is represented by (12) or (14), depending on the zone.
- A slaughterhouse can deal exclusively with average sized pigs, meaning that that the quantity of generated pig meat is represented by (13) or (15), depending on the zone.
- A slaughterhouse can deal with both piglets and average sized pigs, meaning that the quantity of generated pig meat is given by the sum of (12) and (13), in the case of a slaughterhouse located in Lisbon and Tagus Valley; or by the sum of (14) and (15), in the case of a slaughterhouse located in the Centre.

Up to this point, only quantities related to general pig meat generated by each slaughterhouse have been discussed. However, the objective of the entire process is to exclusively collect by-products that are consumed in China, which is just a small percentage of the quantities discussed up to this point. Table 14 presents the live weight percentage of each pig meat by-product that is consumed in China.

Table 14 - Weight distribution of the most consumed by-products by the Chinese citizens [113,114]

By-product	Weight percentage (%)
Liver	1.75
Heart	0.25
Stomach	0.65
Kidney	0.3
Subtotal - Slaughterhouse	**2.95**
Hocks	2.12
Feet	1.85
Tongues	0.35
Ears	0.02
Tail	0.1
Total – MPC + Slaughterhouse	**7.39**

The final distinction to be made is between those that are exclusively slaughterhouses and those that have an integrated meat processing centre (MPC). This is an important difference because there are by-products that can only be obtained from slaughterhouses and there are the ones that can only be obtained from meat processing centres. Therefore, a *pure* slaughterhouse can only provide by-products contained in the subtotal (2.95% of the whole live pig weight), whereas a slaughterhouse that integrates a meat processing centre can provide all the by-products mentioned in Table 14 (7.39% of the whole live pig weight). In conclusion, the volume of by-products that is daily generated in each slaughterhouse under study can be obtained by multiplying the volume of pig meat produced in each slaughterhouse, which was already calculated, by the sum of weight percentages of the by-products presented in Table 14 (the subtotal in the case of a *pure* slaughterhouse, or the total in the case of a slaughterhouse that integrates a meat processing centre). Then, of course, the quantity to be collected depends on the frequency of the collection itself. It is stated in reference [106], which refers to Marta Lopes' dissertation, that the collection process usually occurs every 3 working days (see Annex 4).

4.1.3 Mathematical formulation

First, there are *n* slaughterhouses and *k* vehicles to be considered in this model. Each slaughterhouse is represented by i and j, where i is always different than j. In this case, 0 represents the depot. The other vertices in the graph (i=1,2,…,n) represent the slaughterhouses that must be visited by a truck. A set of vehicles k = {1,…,K} is initially stationed at the depot. All parameters are presented in Table 15.

After all parameters presented in Table 15 and indexes (i and j representing the slaughterhouses and k representing the trucks) are defined, the route optimization is performed considering the chosen cluster of slaughterhouses. The mathematical formulation is presented as follows. First, the decision variable is defined in the following way:

$$X_{ijk} = \begin{cases} 1, if\ vehicle\ k\ goes\ through\ arc\ (i,j) \\ 0, otherwise \end{cases}$$

In addition to the decision variable, there is also the variable u_i. This variable refers to the ordinal position of each slaughterhouse that is visited by a given truck.

Table 15 – Model's parameters

Parameter	Symbol	Description
Vehicle's capacity	Cap	Capacity of each vehicle (kg)
Worker's salary per hour	H	Worker's salary (€/h), knowing that there is only one worker driving each vehicle.
Transportation cost	d	Transportation cost (€/km)
Speed	v	Average speed (km/h) of every truck
Duration of collection	Collection_Duration	Duration of the processing of collecting the goods from each slaughterhouse
Working hours	Working_Hours	Number of working hours performed by each vehicle driver
Distance	$dist_{ij}$	Absolute distance (km) of arc (i,j)
Duration	$time_{ijk}$	Travel duration (h) for each vehicle, associated with traversing arc (i,j).
Quantity of by-products in a slaughterhouse	c_i	Quantity (kg), of by-products in slaughterhouse i
Toll	T_{ij}	Toll value (€) that must be paid in order to traverse arc (i,j)

Before the mathematical formulation is explained, note that the parameter $time_{ij}$ presented in table 15 is defined in the following way:

$$time_{ij} = \frac{dist_{ij}}{v} + Collection\_Duration \quad \forall k = 1,2,\dots,K \tag{16}$$

Equation (16) defines the duration that a given vehicle in the model takes in order to travel arc (i,j). Note that the value of *Collection_Duration* is 0.5 (30 minutes) and it represents the time the worker driving the vehicle takes in order to perform the collection itself within any slaughterhouse the driver passes by [106].

The objective function is described by equation (17), whose main goal is to minimize total travelling costs.

$$Min \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{K}(dist_{ij} * X_{ijk} * d + T_{ij} * X_{ijk} + 2 * H * t_{ijk} * X_{ijk}) \quad (17)$$

Subject to:

$$\sum_{i=1}^{n} X_{ijk} \leq 1 \quad \forall j = 0; k = 1,2, \dots K \quad (18)$$

$$\sum_{i=1}^{n} X_{jik} \leq 1 \quad \forall j = 0; k = 1,2, \dots K \quad (19)$$

$$\sum_{i=0}^{n}\sum_{k=1}^{K} X_{ijk} = 1 \quad \forall j = 1,2, \dots n \quad (20)$$

$$\sum_{i=0}^{n}\sum_{k=1}^{K} X_{jik} = 1 \quad \forall j = 1,2, \dots n \quad (21)$$

$$\sum_{j=0}^{n} X_{ijk} = \sum_{j=0}^{n} X_{jik} \quad \forall i = 0,1, \dots n; k = 1, 2, \dots K \quad (22)$$

$$\sum_{i=1}^{n} c_i X_{ijk} \leq Cap \quad \forall\, k = 1,2, \dots K \quad (23)$$

$$\sum_{i=0}^{n}\sum_{j=0}^{n} t_{ijk} * X_{ijk} \leq 2 * Working\_Hours \quad \forall k = 1,2, \dots, K \quad (24)$$

$$u_i - u_j + N * X_{ijk} \leq N - 1 \quad \forall k = 1,2, \dots, K; 1 \leq i \neq j \leq N \quad (25)$$

The first two constraints, presented by equations (18) and (19), specify all conditions related to the depot. Equation (18) states that each truck must enter the depot at the end of the tour, whereas equation (19) states that each vehicle must leave the depot at the start of the tour. According to equation (20) and (21), each slaughterhouse must be visited and left exactly once, respectively. Then, equation (22) ensures the continuity condition, meaning that, if vehicle k enters a node (slaughterhouse), it must also leave that same node. Then, equation (23) shows that the total collected by-products from all the visited slaughterhouses by each vehicle must not exceed the capacity of the vehicle. Equation (24) imposes a time limitation of *Working_Hours*, which is 8 hours of transport for vehicle driver (it is considered that each truck contains two workers) [106]. Equation (25) represents the Miller, Tucker and Zemlin (MTZ) constrain, which prevents every vehicle to drive in closed circuits that do not contain the depot.

4.2 The second phase: the export of by-products

After all by-products are collected, stored at the depot and then taken to the port or airport of departure, they are ready to be exported and commercialized. This second half of the chapter has two main purposes. The first one is to demonstrate the business potential of the Chinese meat products' market that led the author to believe that the export of pork by-products to China would be a sustainable business opportunity. The second one is to present the two most viable means of transportation for exporting meat products to China: air freight and ocean/sea freight. First, all necessary physical and contractual conditions that must be put into practice in order to guarantee the export of meat products to China will also be mentioned. Then, a demonstration and explanation of all the costs that are usually incurred in the export of meat products, in the cases of both air freight and ocean/sea freight are presented. Finally, the section ends with the demonstration of the chosen incoterm.

4.2.1 International markets

In some countries, variety meats are considered delicacies and are used in many traditional dishes, whereas in other countries, their consumption is associated with low-income populations and is not very demanded. Demand for variety meats is especially high in many Asian countries, like in China, where many recipes include meat by-products rather than muscle cuts, which are not as desired as they are within European cultures. Cow tongues are considered expensive delicacies in Japan and sliced beef feet are used for soup in South Korea, for instance. Tongue and liver are used in many Mexican dishes, such as *putzaze* (tripe and liver with tomatoes), *lengua* (tongue with green chilies), and *menudo norteña* (tripe soup). In Russia and Egypt, two of the world's leading importers of edible offal (head meat, liver, heart, kidney, and tongue), variety meats are more commonly consumed by lower income households and are used as an inexpensive way to obtain high-quality protein and nutrition [91]. To gain insight into the value of variety meats, it is recommended to observe prices for some of the edible by-product in some foreign markets. Table 16 illustrates the difference in value for some pig by-products available in the U.S., Chinese, and Mexican markets. [91].

Table 16 - U.S. - Chinese - Mexican pig meat by-product price comparison [91]

By-product	U.S. average price, 2000-2010	U.S. average price, 2010	U.S. price, week ending May 22, 2010	China price, May 20, 2010	Central Mexico price, May 21, 2010
			Dollars per hundredweight		
Kidneys	19.44	21.71	NA	146.11	NA
Livers	17.23	16.73	NA	51.80	NA
Ears	97.09	134.57	139.00	126.71	NA
Stomachs	65.23	106.85	112.00	112.90	NA
Chitterlings	42.41	NA	NA	83.01	NA
Hocks	29.06	42.73	37.00	69.73	NA
Hearts	33.84	32.47	33.00	89.66	NA
Tails	43.43	66.69	63.80	212.52	NA
Feet	34.97	46.85	51.00	83.01	57.69
Skins	25.00	40.00	NA	53.13	69.92
Tongues	75.97	135.30	122.00	136.14	NA
Head	NA	NA	NA	68.00	54.19
Cheek meat	66.17	93.48	94.70	NA	97.89
Viscera	NA	NA	NA	NA	20.98

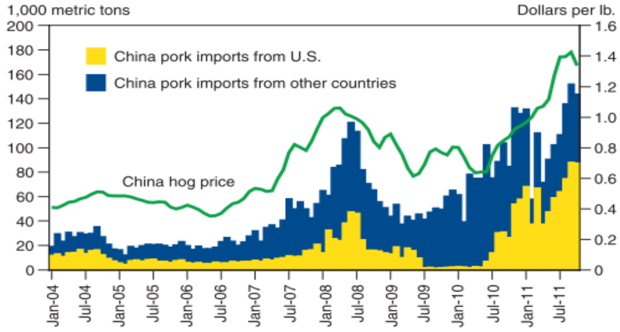
As Table 16 shows, in the United States, the average prices for most of by-products in 2010 are much higher than their respective 2000-2010 averages, thus showing that the prices for these by-products are rising in general. There are some American items that are competitive in the Chinese and Mexican markets. Although transportation costs, exchange rates, and tariffs affect the costs of by-product items imported from the United States, certain goods, such as kidneys, livers, hearts, tails, and tripe, cost more than twice as much in China when compared to the United States.

China's potential as a major pork importer is starting to catch the attention of pig farmers, business leaders, and investors around the world. As China is becoming a very large player in the world pork market, it is highly recommended for industry analysts, business leaders, and policymakers to understand the most important features that drive the Chinese pig meat sector. China's pork industry is constantly affected by many effects, such as disease epidemics, feed prices, policy interventions, seasonal consumption patterns, demand for other types of meat and macroeconomic factors.

4.2.1.1 Chinese meat by-products' market

Most of the information stated in the present dissertation regarding the Chinese meat by-products market is based on the report presented in reference [92]. In that report, the features that make the Chinese variety meats' market such a good opportunity for pig meat exporters are highlighted. Although most of the information presented in the report is related to the existent pork trade between the United States and China, it is believed that the concepts presented by that report are highly applicable in the case of European countries, such as Portugal. China's potentiality to influence the world pork market comes from the size and volatility of its domestic pork market. The country is responsible for nearly half of the world's pork production and consumption. Its annual pork output is between four and five times higher than the United States' and more than the double of the European Union's.

Figure 18 reveals a clear correlation between imports and the domestic pork price. High domestic prices between 2007 and 2008 resulted in short supplies of Chinese domestic pork and demanded for pork imports. Imports then grew up due to a temporary cut in the country's pork tariff and a state-owned company's contract to purchase American pork to build up reserves ahead of the Olympic Games that occurred in Beijing in August 2008. Then, many factors lower the prices in first half of 2009: an increased domestic supply that occurred due to a buildup in production capacity and a temporary decrease in demand due to some concerns among Chinese consumers that the swine flu could be transmitted through pig meat. Although no relation between pork consumption and the swine flu transmission was ever proved by scientists, Chinese authorities stopped importing pork from North America in order to prevent the spread of the disease to China. This policy remained until June of 2010. Chinese pig meat prices began to increase once again in the second half of 2010 as they reached their highest values, according to Figure 19, during 2011. Because of the increased domestic pork prices, the less costly foreign pork became competitive in the Chinese market.

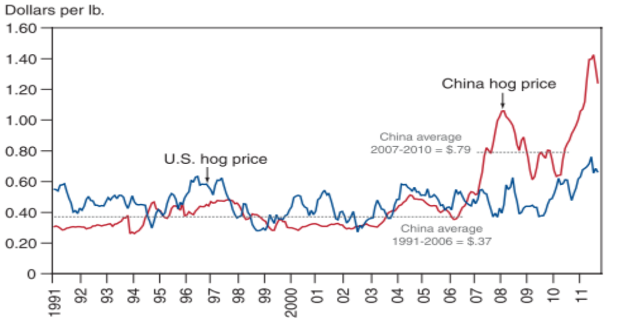


Note: Data include fresh, chilled, and frozen pork; sausage casings; offal; and processed pork products (Harmonized System codes 0203, 020630, 020641, 020649, 0210, 0504, 160241, 160242, 160249). China hog price converted to U.S. dollars at the official exchange rate.

Source: USDA, Economic Research Service using data from China National Bureau of Statistics and China customs statistics accessed through Global Trade Information Service, Global Trade Atlas.

Figure 18 - How China's monthly pork imports vary with domestic hog prices [92]

The high prices associated with China's domestic pork market were the main reason for the country's increase in pork imports. After the large increase that occurred between 2007 and 2008, Chinese hog prices have been significantly higher than American ones, as Figure 19 illustrates



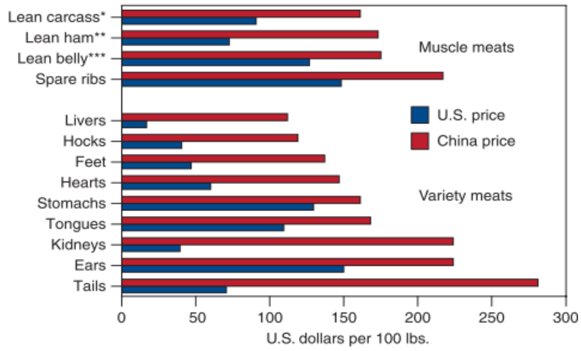
Note: U.S. live hog equivalent, 51-52 percent lean. China price converted to U.S. dollars at official exchange rate. Prices are not adjusted for inflation.

Source: USDA, Economic Research Service using data from USDA, China National Bureau of Statistics, and China Ministry of Agriculture.

Figure 19 - Comparison between the U.S. and China hog prices [92]

The shift in prices is clear sign of the general improvement of imported pig meat sales in China. However, to be cost competitive in China, it is not enough for the foreign hog to be cheaper than the Chinese hog. The cost of foreign pig meat, summed up with freight costs, tariffs (between 12 and 20 percent), and value-added taxes (between 13 and 17 percent), must be equal or lower than the cost of Chinese pork. To conclude, in the case of the United States, it is estimated that prices of Chinese pork would have to be approximately 30 to 45 percent higher than the price of American pork for it to be cost competitive in China.

European/American and Chinese consumers have complementary tastes that potentiate the trade of pork products between both groups. American and European consumers prefer muscle meats, whereas Chinese consumers prefer by-products that have low value in the United States and Europe (observe Figure 20). In 2011, the average American prices of livers, hearts, hocks, feet, kidneys, and tails were less than half the prices of their correspondents' in a Beijing wholesale market. In 2011, the rise in Chinese pig prices drove the prices of both muscle meats and variety meats much higher than the prices from the United States. Most of the American pork exported to China is constituted by by-products, but the significant price difference that exists in muscle meats proves that American muscle meats can also be competitive in the Chinese market.



Note: U.S. average price, January-May 2011; China average price from Xinfadi wholesale market, May 2011.
*China lean carcass (bai tiao rou) is compared with U.S. 53-54 percent lean, .65-.80 inches of backfat at last rib.
**China lean ham (hou tun jian) is compared with U.S. composite primal ham.
***China lean belly (wu hua rou) is compared with U.S. composite primal belly.
Source: USDA, Economic Research Service using USDA, Agricultural Marketing Service, LGM Portal database and Beijing Xinfadi Wholesale Market "price quotations."

Figure 20 - Comparison of prices of pork parts, U.S. and Beijing (China) averages, 2011 [92]

Although there is a wide variety of feeds for domestic hog production, Chinese pig market analysts pay special attention to the price of corn, which is usually higher in China, as it is used as an indicator of feed costs (therefore, hog production costs). When corn prices are really high, thus raising the cost of pork production in China, industry members may consider two points of view in order to mitigate cost pressure:

1. Import corn from other countries with lower corn prices in order to lower the cost of Chinese pork production;
2. Import foreign pork that might be produced based on lower feed costs.

Meeting Chinese demand for pork by producing it in other counties and then exporting it to China proved to be more cost-efficient than exporting large volumes of corn and other feeds to produce pork in China. The question that remains is whether it is also financially feasible for China and Portugal to commercialize Portuguese pork by-products.

4.2.1.2 Business opportunity

This last section presented several Chinese pork market characteristics that show how exporting pig by-products to China could be a real business opportunity. This opportunity can, not only be profiTable for the Portuguese company that exports such products, but also satisfy the needs and tastes of Chinese pork consumers.

First, as it is stated in the previous section, it can be less costly for Chinese pig meat industry entities to import directly from other countries than to produce domestic pig meat. Therefore, with the rise of domestic pork prices, the less expensive foreign pork becomes more competitive in the Chinese market. However, to be cost competitive in China, foreign pig meat must be comparable in cost or cheaper than Chinese pork after accounting for freight costs, tariffs, value-added taxes and so on. On the other hand, the profit deriving from the exportation of pig meat products, considering all the costs involved in the process and the price at which the products will be sold, must be positive for the exporting entity.

Lastly, the EU countries and Chinese consumers have complementary tastes that encourage pork trade between both groups. European consumers prefer muscle meats, while Chinese consumers prefer offal and variety meats that have low value in the EU countries. By analyzing Figure 20 again, the fact that the price of most variety meats is much higher in China than in foreign countries is notorious.

These features of the Chinese variety meats' market are what makes it such a promising opportunity for exporters, importers and all the citizens from the exporting and importing countries to benefit from it. The exporting company wins because it has found a new business opportunity that could be beneficial in financial terms. The importer wins by finding a supplier that provides a type of product that is highly consumed in the importing country, at a potentially lower price. The citizens of the importing country win because there is now a greater offer for a type of product that is highly consumed. The citizens of the exporting country win because the repercussions of potentially wasting a large volume of meat, which could harm the country, financially, environmentally and socially, have been avoided.

The following sections lead us to answer the following question: how are the collected by-products going to be exported? Many options must be analyzed, especially regarding the Incoterm to be established with the importer, the way of transportation and the quantity to be exported. The quantity of export by-products mostly depends on the quantity demanded by the importing company. The way of transportation depends on factors such as:

- The required speed of transportation, which is related to deadlines imposed by the importing company (or companies) and the perishability nature of the exported products;
- Demand, which refers to the quantity ordered by the importing company (or companies) located in China;
- The cost that the exporting company is willing to support.

After making all the decisions regarding the Incoterm, which way of transportation will be adopted, the quantities to be exported and so on, the cost of exportation will be computed. After getting all the costs involved in the entire process, since the by-products started being collected until they have officially reached the port of destination located in China, the final cost can finally be obtained. The values of all costs are explained throughout the present chapter and they were obtained through websites, articles and reports.

4.2.2 Conditions to export meat products to China [93]

Reference [93] presents a report that provides insights regarding all conditions and protocols that must be met in order to trade meat products with China. The Food Safety Law defines a new approach to food safety in China by providing a legal framework for production and trade of food products. Any business dealing with the food industry and wanting to export meat products to China must meet the Chinese Food Safety Law provisions. The main goal of the Food Safety Law is to implement surveillance and a tracking system for food products being commercialized, from its origin to its consumption.

Protocols consist on formal agreements between the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) of China and the food safety departments belonging to the exporting country that must meet all veterinary and health requirements for meat products to be exported to China. Protocols transfer the responsibility for inspection measures on meat products being exported to the authorities belonging to the exporting country.

Protocols have a standard content. The most common relevant provisions approached by these protocols are the following:

- Exporting authorities provide AQSIQ with the management regulations and procedures affecting processing plants and the control system related to diseases and confirm that the country is an epizootic-free area.
- Exporting authorities ensure control for all meat products and ensure that any product carries specified diseases. AQSIQ must be notified in case of any contagious occurrence and, in those cases, the exporting process ceases immediately.
- Details on the registration of the exporting entity by the Certification and Accreditation Administration of the People's Republic of China (CNCA).
- The main responsibilities to be performed by official veterinarians of the exporting country.

- The guarantee that slaughtering and processing plants can only operate on meat products that comply with requirements.

In the end, each entity included in the meat supply chain must be registered in the current list of approved entities by the Chinese veterinary authorities, which include slaughterhouses, cold stores, meat processing centers and so on.

4.2.3 Physical conditions to export meat products

Meat by-products are extremely vulnerable to microbiological hazards, since their moisture, pH levels, and high protein content provide the kind of environment that best allows the growth of bacteria. Due to these characteristics, the products must be carefully monitored in order to prevent their exposure while being stored during transportation [108].

Generally, frozen meat is stored under a temperature of -18ºC so that the activity of micro-organisms and enzymatic degradation are properly suppressed (the temperature can be lower as long as it is maintained, in order to avoid re-crystallization, which originates the degradation and discolouration of the meat). For that temperature, edible offal has a practical storage life of 4 months. An important note is that the temperature of the meat products must be constantly tracked through measurement at regular intervals. The temperature must be kept constant in order to avoid re-crystallization on the product's surface, which reduces the utility value. This means that the interruption of freezing, resulting in warming and refreezing the products must be avoided at all costs [109,110].

Regarding the package, sides of pork are usually packaged in stockinet and boned portions are wrapped in film and then packaged in cartons. Offal is often vacuum-packed. The protective coverings must always be clean and dry, meaning without blood stains, since they are a sign of previous thawing [109,110].

Weight loss through water evaporation can occur. Relative humidity in the storage space should be kept at 95% in order to prevent the surface of the meat from drying out. Sublimation proceeds constantly at the surface of frozen meat. This can be seen as freezer burn, which means superficial desiccated areas which can occur even in packaged meats when the packaging film is loose, and temperature fluctuates inside the chamber or container. Meat surface can dry and become porous, encouraging rancidity and the transfer of aromas. This drying process should be avoided because the shrinkage damages the surface appearance. In extreme cases, surface drying may result in freezer burn, an effect which may be counteracted by plastic film packaging. Weight loss usually results in a mark down of the product's price. There is also the concern related to the fact that meat absorbs foreign odours. For instance, freshly painted areas may be rejected due to the odour of paint. Additionally, meats from different species of animals should not be stowed together, as their characteristic odours may cause odour tainting [109,110].

Frozen meat products are also extremely sensitive to contamination. Therefore, containers must be thoroughly clean. It is recommended that the level of cleanliness of the container is confirmed by an inspector before the loading [109,110].

Regarding the negative mechanical influences, accidental droppings or shocks may result in breakage. The products are also sensitive to slipping due to poor stowage. Chafing of solidly frozen meat may result in damage to film packaging. Meat packaged in cartons must be secured in the container in such a way that it cannot move during the entire trip. In the case of container transport, it is also important for the goods to be secured in the door area so that they cannot fall out of the container when the doors are opened [109,110].

4.2.4 International costs

In the present dissertation, two transportation options will be considered: air freight and ocean/sea freight. The main cost components related to the movement of goods from the exporting to the importing countries will be discussed, for the both of the above-mentioned means of transportation. In addition, all cost procedures related to the arrival of meat products to a Chinese port will be exhibited.

4.2.4.1 Air freight

Air freight is commonly used when the goods being transported are small and high value, or urgently required [96]. The costs of air freight are significantly higher than those associated with sea freight and are usually calculated based on weight, unlike the case of sea freight, where they mostly based on the number of containers being transported. There are some types of goods that are generally shipped via air freight: urgent goods, perishable goods, live animals, pharmaceutical products, medical supplies, seasonal products, luxury products and so on [92]. In this case, pig meat by-products are inserted in the perishable products, and that is why this mode of transportation is currently being considered. There are three main choices regarding the arrangement of an air freight delivery [96,97]:

- Consolidated freight – one flight contains different shipments;
- Back to back or direct services - a single shipment is transported by a scheduled plane;
- Charter services – occasionally, entire freight planes can be chartered for a single service. This service is very costly.

Air freight pricing is usually based on the weight of goods being moved. However, if particularly large or oddly shaped objects are being shipped, this might incur some surcharges related to low levels of stowability. Using a consolidated freight route is usually the cheapest arrangement, although it might take a few days longer than a direct service. Air freight costs vary significantly depending on what it is being moved and to where. The following considerations must be taken into account when defining the cost of air freight [98,99]:

- Base rate - As a general starting point, carriers use a shipment's weight when calculating cost. There are two options regarding the type of weight to use when computing the base rate: the actual weight, that is, how much the item actually weighs (gross weigh); volumetric weigh (or dimensional weigh) which is calculated by dividing the volume of the item by the density of the item.
- Fuel surcharge (FSC) – it is a fee that is related with the fluctuation and seasonality associated with fuel costs. This cost component is one of the top expenses for carriers. Fuel surcharges depend on the fuel's price and are calculated as a percentage of the shipment's weight.
- Security surcharges – it refers to any additional fees for security measures required at airports. The cost associated with security surcharges applies to evaluation processes that certain goods must go through in accordance with the Airline Security Regulations. The fee is charged at the points of origin and destination and are exclusively applied to air freight rates
- Container freight station (CFS) – it is a fee that is related to cargo that is temporarily stored in third-party warehouses or other facilities when entering a country. Once all necessary customs documentation is provided, all cargo is released.
- Airline terminal handling fees – these are charged in order to compensate all costs associated with cargo handling at the origin and destination ports.

Additionally, in the case of door-to-door services, the following costs must also be considered:

- Custom clearance fees – these are referred to charges paid to customs brokers in order to allow the entrance of the exported goods into the country of destination.
- Associated trucking fees – they are charged when cargo is picked up from the airport and transported to the next stop. These fees are charged in order to cover fuel costs and drivers' wages.
- Cargo insurance – typically arranged through a freight forwarder and covers all cargo being exported. Cargo insurance is highly recommended, since liability falls on the shipper, not on the carrier or forwarder.

4.2.4.2 Ocean/Sea freight

Ocean/sea freight transport is the shipping by sea or ocean via of goods inserted in shipping containers and it is currently the most common mode of transport that importers and exporters use [101]. Ocean and sea freight can be divided into the two following options: a full container load (FCL) and a less than container load (LCL). One important factor is the choice between FCL or an LCL. With LCL, several shipments are put into one container, which usually means more work for the forwarder. In the cases of

LCL, there is more paperwork involved, as well as the physical work of consolidating various shipments into a container before the main transport and the shipments' de-consolidation at the destination port. The LCL shipments contain three main disadvantages:

1. LCL takes more time to deliver than an FCL shipment, due to all the extra work involved.
2. The risk of damaging, misplacing, and losing the goods is higher.
3. The cost per cubic meter is higher.

Ocean freight quote is dependent on factors such as the form of cargo, the mode of transportation, the weight of the cargo, and the distance between the ports of departure and destination. Some of the costs of shipping sea freight are related to where the goods come from and where they go to. Freight costs are often broken down into three main categories: pre-carriage, carriage and post carriage. Pre-carriage costs include all those inherent to the inland movement (often close to the port) that are incurred before the container is loaded at the port of departure. The carriage costs refer to the ones incurred while moving the cargo between the port of loading and the port of discharge. Lastly, the post carriage costs refer to any in-land movement that occur after the container is off-loaded [103]. A breakdown of ocean freight quote components is presented in Table 17.

Table 17 - A breakdown of ocean freight quote components. Adapted from [103]

Cost category[1]	Name of the cost[1]	Description[1]
Pre-carriage	Chassis utilization surcharge[2]	Surcharge charged by the line for the usage of the chassis for the cartage and, as part of this movement and depending on the weight of the cargo, a tri-axle surcharge for weights exceeding the road limits may also be charged
	Cartage charges[2]	A charge for transporting goods within short close areas.
	Fuel Surcharge[2]	Surcharge imposed on the fuel being used for the transport of the shipment
	Packing charges	A fee that may be charged by another entity for packing the cargo into the container. If the packing is performed by the shipper, this fee is not applied
	Customs Clearance[2]	It is a fee that is paid to the customs broker for taking care of the exporter's customs clearance
	Wharfage[2]	A charge imposed by the dock owner against freight handled in that dock or against a shipping company using such dock.
	Documentation charges[2]	Charges that may be imposed for the preparation of export documentation.
Carriage	Ocean Freight Rate	Freight charge for the movement of all containers from the load port to the destination port.
	Bunker Adjustment Factor (BAF)	It is used to compensate the fluctuation of fuel costs.
	Terminal Handling Charge (THC)	This charge refers to the costs associated with the terminal provider's property. The costs covered include access, equipment maintenance, equipment use, and labour.
	Bill of Lading Fee	A bill of lading is a legal document issued by a carrier to a shipper that details the type, quantity, and destination of the goods being carried.
	Export Service	Service fee that can be charged by the agent.

	Documentation Fee	It covers the cost that freight forwarders must pay to carriers
	Emergency Bunker Surcharge (EBS)	A surcharge that is implemented by carriers to further cover the cost of rising fuel prices.
	International Security Port Surcharge (ISPS)	It is charged in order to guarantee the security of the vessel and container while at the port.
	Environment Fee Destination	It is a charge that covers many environmental contingencies such as hydrocarbon spill cleaning costs and others.
	Equipment Repositioning Surcharge (ERS)	It is for when there is a need to position empty containers at a certain place for exports.
	General Rate Increase (GRI)	It is the increase of the base rate that is imposed by the carrier. It is usually a result of an increase in demand.
	Hazardous surcharge	A surcharge imposed for transporting hazardous goods.
	Overweight Surcharge	It is for overweighed containers.
	Piracy Surcharge	It is for costs applied to certain routes where precautions must be taken to avoid piracy.
	Peak Season Surcharge	This surcharge covers incremental operational costs incurred during the peak season.
	Currency Adjustment Factor (CAF)	A charge that is imposed in order to compensate ocean carriers for currency fluctuations. It is a percentage of the base rate.
	Port Dues	Fees charged by destination port's authority on vessels for entering the port's facilities.
	Destination Delivery Charge (DDC)[2]	An additional fee charged by the carrier, based on container size, that is applied in order to upset the cost of cranes usage and gate fee at the terminal.
	Detention and Demurrage[2]	These charges occur when the carrier's containers are not delivered back within the allowed free days. The free days refer to the number of days a shipper can use the container for free. If the free time is exceeded, the user must pay these charges. Those are usually calculated per day. Demurrage is applied for cargo whereas detention is applied to equipment
Post Carriage	Unpacking charges	A fee that may be charged by a separate entity for unpacking all cargo from the container at their premises. If cargo is unpacked directly at the consignee's premises, this charge is not imposed.
	Container Yard Receiving Charge (CYRC)	Fee charged to a shipping line for receiving it from the ship, storing and delivering it to the consignee at the destination port.
	Destination Terminal Handling Charge (DTHC)	This refers to all costs related with the destination terminal provider's property.

		These include access, equipment usage and maintenance, and labour.
	Handling fee	A fee for staff costs, storage, administration and handling the goods.
	Release fee	A fee charged by the port of destination in order to release all cargo for further action.

[1] [103]
[2] May be charged at the destination port instead, thus being considered Post carriage costs in those cases

4.2.4.3 Costs after arrival at a Chinese port (Qingdao example)

The costs presented in Table 18 refer to the ones inherent to all import procedures after the arrival at the Chinese Port. The costs were found on the report stated in reference [93], which used the Qingdao port as an example.

If the import agent receives complete documentation before the shipment arrival, that entity can start the inspection procedures to shorten the clearance time. This usually takes between one and two days. When cargo arrives at the port, the clearance process steps are the ones presented in Table 18. After the shipment arrival, the containers are stored in the port yard. After the commodity inspection (1), the import agent delivers the container to the warehouse authorised by "Qingdao Entry - Exit Inspection and Quarantine Bureau". The import agent then goes to the shipping company to obtain the D/O (delivery order), after paying the imposed fees and charges (3 to 7), usually taking about 1 day. Then, the import agent submits D/O and other documents to customs so that the customs clearance is able to begin (8 and 9), which usually takes about between 3 and 5 days. The import agent then pays port charges to the port of arrival and starts handling delivery procedures (10 and 11), usually taking about a day. After, empty containers return to yard specified by the shipping company (12 to 15), taking 2 days. Import agent fees account for approximately 1.5% of cargo value. Finally, the goods are free to go.

Table 18 - Costs after arrival at Chinese port (Qingdao example). Adapted from [93]

Costs after arrival at Chinese port	Value
1. Commodity inspection	RMB200/BL[1]
2. Quarantine inspection fee	0.8 ‰ of total value of goods
3. D/O (delivery order)	RMB300-350/BL
4. THC (terminal handling charge)	RMB1280/40RF[2]
5. Documentation fee	RMB100-400/BL
6. Handling charge	RMB200-400/40RF
7. Mechanical fee	RMB100-200/40RF
8. Customs declaration	RMB200/BL
9. Import tariffs	%* on the CIF[3] price of the goods
10. Port charge	RMB500/40RF + storage charges
11. Refrigeration charge	RMB600/40RF (within 5 days) + RMB100/40RF/per day (if more than 5 days)
12. Delivery	at cost
13. Inspection agency fees	RMB300/BL
14. Handling charge	RMB200/BL
15. Storage charges, demurrage charges, container maintenance fee, cleaning fee at cost	at cost

[1] BL= Bill of lading
[2] RF = Refrigerated (reefer) containers
[3] CIF = Cost, Insurance and Freight, the price of the goods including insurance and freight

4.2.5 Incoterm

As it is known, there is no standard Incoterm that can be applied to all situations that involve international commerce. Instead, the exporting and importing entities must negotiate an Incoterm that satisfies both, thus meeting the requirements of each one. Regarding the exporting side, sometimes the exporter wants to control and keep track of international shipping costs all the way to the destination port, since this way provides the exporter flexibility to implement cost-effective shipping options, that is, the most efficient routes, rates, transit times and so on. However, when the exporter does not feel too familiar with the laws and trading regulations of the country of destination, it is better to transfer the responsibility for the goods to the importer at the terminal of destination. However, one must notice that the greater the control one company has over the international trade, the greater the responsibility and the greater the risk for that same company. The same logic can be applied for the importer. When negotiating, both parties must reach an agreement that is beneficial for both and they must guarantee that all responsibilities are properly defined in order to avoid future problems. In the context of this dissertation, DAT (Delivery at Terminal) was the chosen Incoterm so that the author can put into practice all the costs referred throughout the previous sections of the present chapter. This Incoterm is used when it is the seller's responsibility to fully deliver the goods at the port of destination [94,95]. The seller is accountable for all the expenses, risks and insurance incurred until the goods are unloaded at the port of destination. On the other hand, the buyer pays for customs clearance and taxes at destination. The seller is still responsible for any destination terminal handling charges. The DAT incoterm can be implemented for any type of product and for every mean of transportation [94,95]. Table 19 presents the obligations for each side of the international transaction in greater detail.

Table 19 - Responsibilities of each party when implementing the DAT incoterm. Adapted from [95]

	Seller's obligations	**Buyer's obligations**
Provision of goods	Delivery of the goods, the invoice and proof of delivery.	Payment of the delivered goods.
Licenses	Deliver the export licenses and authorizations.	The buyer must have an import permit.
Shipping and insurance	Any contract related to the transport of goods, as well as the insurance obligations are the seller's responsibility.	No obligation.
Delivery of goods	The seller must deliver and unload the goods at the upon-agreed time and place.	The buyer must take the goods at the upon-agreed time and place.
Risks	The seller is responsible for the goods until they are unloaded at the terminal.	The buyer is responsible for the goods once they have been unloaded at the terminal.
Costs	The seller must pay for the cost of the main transport, loading of goods at the country of origin, export clearance, unloading of the goods at the country of destination.	The buyer purchases the goods and also pays for import customs duties and taxes.
Notice to the buyer and the seller	The seller must inform the buyer that the goods have been delivered.	The buyer has to provide clear information regarding the tame and place of delivery.
Proof of delivery	The seller must find a way of knowing and proving that the goods have been properly delivered in a document and then provide the buyer that same document.	No obligation.
Checking and inspection	The seller must control and track the quality, the weight, and the packing of the goods throughout the entire exporting process.	No obligation.

4.3 Chapter conclusions

The main objective of this chapter was to demonstrate a methodology capable of explaining step by step how pig meat by-products can be collected and exported to China while explaining why this idea has the potential of being beneficial for all the parties involved.

The first phase of the methodology (section 4.1) provided all the reasoning that was put behind the process of collecting pork by-products from several slaughterhouses located throughout Lisbon, Tagus Valley and the central area of Mainland Portugal and the storage of such products. Throughout these sections, the most relevant costs incurred in the collection and storage processes were mentioned and explained. Also, the methodology that the author applied in order to obtain all necessary data regarding the locations of all slaughterhouses as well as the quantity of by-products that each one was thoroughly explained. Finally, the section ends with the analysis of the mathematical model implemented by the author in order to find the best set of trajectory-trucks that provide the minimum collection cost. The second phase of the methodology (section 4.2) had as main goals the following ones. First, it was to present all the Chinese pork by-products' market features that led the author to believe that the export such products would make a good business opportunity and how it could be highly beneficial to all the parties involved. Then, it was to thoroughly explain the main documental and physical conditions that must be implemented in order to be able to export such perishable products as pig meat by-products. Additionally, it was to show the two main means of transportation when it comes to exporting edible meat by-products to China: air freight and ocean/sea freight. The main idea here was to explain the main features as well as the costs involved in both means of transportation. Finally, it was to present the Incoterm DAT, which was the one chosen by the author.

The next step, which will be presented in the Chapter 5, will be to implement the methodology explained in the present chapter, by using data in order to calculate the final cost of exporting pork by-products to China and to figure out if the revenues generated by the sale of such by-products are large enough to offset all the costs involved in the two discussed phases.

5. Implementation and results

The main goal of the present chapter is to implement the methodology which was proposed in the previous chapter. The structure of this chapter is similar to the last chapter's, as it is also divided into two phases: the collection of by-products from the slaughterhouses and their storage; and the export of the collected by-products to China.

Regarding the first phase, in the collection process, the mathematical model presented in section 4.1.3 was implemented in the software GAMS, using the data stated in section 4.1.2, in order to obtain the best set of trajectory-trucks which find the minimum collection cost. Regarding the second phase, more specifically, the exporting process, the costs which are expressed in sections 4.2.4.1 (in the case of air freight), 4.2.4.2 (in the case of ocean/sea freight) and 4.2.4.3 (which refer to the costs that are incurred at a typical Chinese port when a shipment arrives) are applied on all collected by-products, which are intended to be transported from Lisbon (Portugal) to Qingdao (China). The main objective of this chapter will be to finally implement a cost/benefit analysis by balancing the sum of all the costs incurred throughout the entire export processed that was described in the previous chapter with the expected revenues generated by the sale of such by-products in China. In addition, a sensitive analysis regarding the relationship between the costs spent by the exporter and the frequency of collection of pig meat by-products from those slaughterhouses (which lead to different quantities of goods being exported) will be implemented.

5.1 The volume and value of the collected by-products

After applying the calculations explained in section 4.1.2 on every slaughterhouse registered by the author, it was possible to obtain the accumulated quantities of pork by-products generated by each slaughterhouse after three working days. Then, after analyzing the distances between every slaughterhouse, **three scenarios** were created:

- **Scenario 1** – All slaughterhouses are considered, meaning that all by-products generated by all 50 slaughterhouses after three working days are collected by the trucks;
- **Scenario 2** – Only the slaughterhouse that is located the furthest from the depot is rejected. All the other 49 slaughterhouses are considered;
- **Scenario 3** – Only the slaughterhouses located in the Lisbon/Tagus Valley zone are considered. All slaughterhouses located in the central zone of Portugal are rejected.

Naturally, rejecting and including slaughterhouses in the VRP route have implications on the quantity of collected by-products that will later be exported and, therefore, on the revenues generated by the sale of such by-products in China. Such quantities and revenues are presented in Table 20.

Table 20 - Volume (Kg) and value (€) of all by-products generated by the chosen slaughterhouses

By-product typology	Generated volume in 3 days (Kgs)			Price per kilogram (€/kg)	Value (€)		
	Scenario 1	Scenario 2	Scenario 3		Scenario 1	Scenario 2	Scenario 3
Liver	25 396	24 998	20 660	0.21	5 333	5 250	4 339
Heart	3 628	3 571	2 951	0.35	1 270	1 250	1 033
Stomach	9 433	9 285	7 674	0.44	4 150	4 085	3 376
Kidney	4 354	4 285	3 542	0.57	2 482	2 443	2 019
Hocks	27 508	27 026	22 481	0.27	7 427	7 297	6 070
Feet	24 004	23 584	19 618	0.32	7 681	7 547	6 278
Tongues	4 541	4 462	3 712	0.53	2 407	2 365	1 967
Ears	260	255	212	0.49	127	125	104
Tail	1 298	1 275	1 060	0.83	1 077	1 058	880
Total	**100 420**	**98 743**	**81 910**		**31 954**	**31 420**	**26 066**

In order to find out how valuable such collected by-products are when sold at the Chinese market, the author decided to use the prices which were previously presented in Table 16, more specifically in the column that refers to the price for which all by-products presented in such table were sold in the May 20th of 2010, in China. Table 20 presents such prices, translated into euro per kilogram. Then, by multiplying the generated volumes by the price per kilogram of each typology of pork by-product, the prices for which all by-products are being sold in China were obtained, as they are presented in Table 20.

Now that the quantity, as well as the value of the goods that are being exported are properly defined, the main goal of the following sections of the present chapter is to calculate and present all the costs involved in the processes of collecting, storing and exporting such products, so that a cost/benefit analysis of the proposed methodology can finally be applied.

5.2 The first phase: the collection and storage of by-products

The purpose of the present section is to explain how the model presented in section 4.1.3 was implemented in the software GAMS, as well as to present all the relevant results. First, the values of all scalars (one-dimension parameters) which were implemented in the model will be demonstrated. In addition, the way how all parameters' values were imported to GAMS will be explained. Then, all results will be properly demonstrated and analyzed. Finally, the section ends with a demonstration of how the storage costs were calculated, as well as the cost of transportation between the depot (s0), which is the ETSA's meat processing facility located in Loures, and the port of departure, which can be the maritime port or the Lisbon airport, depending on the chosen way of transportation.

5.2.1 Implementation of the mathematical model in GAMS

As it was stated in the introductory part of the present chapter, the mathematical model which was demonstrated in section 4.1.3 was implemented in the software GAMS. To do so, values had to be attributed to scalars, as well as to all the parameters. Table 21 demonstrates the value that was given to each scalar.

Table 21 - Value attributed to each model's scalar

Scalar	Symbol	Value
Capacity of each vehicle (Kgs)	Cap	32 000
Transportation cost (€/km)	d	1.15
Average speed of every truck (km/h)	v	80
Salary of each worker (€/hour)	H	5.54[1]
Working hours	Working_Hours	8
Duration of each collection (hours)	Collection_Duration	0.5

[1] [137]

Regarding the values that were given to all parameters, all of them, except for $time_{ij}$ (see section 4.1.3), were read and imported to GAMS from Excel (see Annex 5 and Annex 6). Basically, while all the information related with the distances between all slaughterhouses ($dist_{ij}$), the tolls that must be paid in order to move from one slaughterhouse to another (T_{ij}), as well as the quantity of by-products generated by each slaughterhouse (c_i), were presented in Excel files through tables, a function that is able to read and import all that information was implemented in GAMS so that the program could run the model using the appropriate values. All the available vehicles started their routes at the depot, which is the ETSA's meat by-products collection point located in Loures, Lisbon (observe Figure 3).

5.2.1.1 Scenario 1 - All the registered slaughterhouses are included

The results came out after running the model in GAMS (see Annex 7) for 14 400 seconds (equivalent to 4 hours). Five trucks were used. Each truck whose route took more than 8 hours had 2 workers, whereas the ones whose routes took less than 8 hours had one worker/driver. In that sense, it was considered that, when needed, there were two workers in a vehicle so that they could both drive and help each other carrying the collected by-products from the slaughterhouse to the truck. The main model's results are demonstrated in Table 22.

Table 22 – Scenario 1 main results

Truck	Duration of collection (hours)	Truck's final load (Kg)	Truck's final load (%)
K1	11.1 h	494	1.5%
K2	5.9 h	24 294	75.9%
K3	7.8 h	17 943	56.0%
K4	14.8 h	29 511	92.2%
K5	15.3 h	28 179	88.1%

Given that all trucks leave at the same time, the duration of the entire collection process corresponds to the duration of the truck which took the longest time to complete its route. Therefore, in this case, the duration of the collection process as a whole is 15.3 h, which is approximately equivalent to 15 hours and 20 minutes. The result of the model's objective function, whose main goal was to minimize the total cost of the entire collection process, was **3 182 €**. The routes performed by each truck can be observed in Annex 9. In addition, the model statistics are presented in annex 10.

5.2.1.2 Scenario 2 – The furthest slaughterhouse from the depot (s0) is rejected

Just like in the previous scenario, the results came out after running the model in GAMS (see Annex 8) for 14 400 seconds (equivalent to 4 hours). Four trucks were used. Once again, each truck whose route took more than 8 hours had 2 workers, whereas the ones whose routes took less than 8 hours had one worker/driver. The main model's results are demonstrated in Table 23. The routes performed by each truck can be observed in Annex 9. In addition, the model statistics are presented in annex 10.

Table 23 - Scenario 2 main results

Truck	Duration of collection (hours)	Truck's final load (Kg)	Truck's final load (%)
K1	15.5 h	24 897	77.8%
K2	6.0 h	24 293	75.9%
K3	14.7 h	20 042	62.6%
K4	14.9 h	29 511	92.2%

By the same logic as the one used in the previous scenario, given that all trucks leave at the same time, the duration of the entire collection process is 15.5 h, which is approximately equivalent to 15 hours and 30 minutes. The result of the model's objective function, whose main goal was to minimize the total cost of the entire collection process, was **2 913 €**. By analyzing the resulting cost and duration, one can understand that, timewise, the duration of scenario 1 is slightly lower than the duration of scenario 2, by a margin of 10 minutes. Cost wise, the present scenario is better than scenario 1 by a margin of 269 €.

Just by analyzing the revenues demonstrated in Table 20 and the collection costs for scenarios 1 and 2, one can observe that the profit for scenario 1 is 28 772 € and 28 507 € for scenario 2. Therefore, profit wise, scenario 1 is better than scenario 2 by a margin of 265 € (admitting that only collection costs are being considered).

5.2.1.3 Scenario 3 – All slaughterhouses outside the Lisbon/ Tagus Valley zone are rejected

The main goal of this third scenario is to provide an alternative for a case of an urgency, that is, a case in which, for some reason, the exporter was not able to collect the planned quantity of by-products (weather it was because of the collector, who was not able to start the collection process earlier and must ship the goods on a previously agreed date, or because some slaughterhouses were not able to provide the pre-agreed quantity of by-products). In this scenario, all slaughterhouses located outside the Lisbon/ Tagus Valley zone are rejected so that the collection duration can be lower than 8 hours. This process will, not only be shorter in terms of duration, but it will also be much cheaper, because, in this case, there is only one worker driving the truck.

Just like in the previous scenarios, the program run in GAMS (see again Annex 7) for 14 400 seconds (equivalent to four hours). Only three trucks were needed. The model's results are demonstrated in

Table 24. The routes performed by each truck can be observed in Annex 9. In addition, the model statistics are presented in annex 10.

Table 24 - Scenario 3 main results

Truck	Duration of collection (hours)	Truck's final load (Kg)	Truck's final load (%)
K1	5.6 h	27 602	86.3%
K2	5.9 h	24 293	75.9%
K3	8.0 h	30 015	93.8%

By the same logic as the one used in the previous scenario, given that all trucks leave at the same time, the duration of the entire collection process is 8 hours. The result of the model's objective function, whose main goal was to minimize the total cost of the entire collection process, was **879 €**. By analyzing the resulting duration, one can understand that the duration of scenario 3 is much lower than the duration of the two previous scenarios, by a margin of 7 hours and 20 minutes when comparing to scenario 1. Cost wise, the present scenario is also much cheaper than the previous two scenarios, by a margin of 2 034 € when compared to scenario 2. The profit of scenario 3, if only accounting for the collection costs, is 25 187 €, thus being lower than the ones of the two other scenarios.

5.2.2 Warehousing costs and transportation of the collected goods to the port or airport of departure

In order to obtain an estimate regarding the cost of storing the collected pork by-products, the author contacted Greenyard, a company which was described in section 2.3.3. This company is well known for its expertise when it comes to storing goods.

When contacting Greenyard, the author was told that the main costs vary according to the number of pallets being handled and stored. Knowing that each pallet can carry between 600 and 750 Kgs of products, the author decided to use the average of the two weights: 675 Kgs. The calculations which were implemented in order to obtain the main costs are presented in Table 25.

Table 25 - Warehousing costs

	Cost formula	Scenario 1	Scenario 2	Scenario 3
Number of used pallets	-	$\frac{100\ 420^{1}\ Kgs}{675\ Kgs} \cong 149^{2}$	$\frac{98\ 473^{1}\ Kgs}{675\ Kgs} \cong 147^{2}$	$\frac{81\ 910^{1}\ Kgs}{675\ Kgs} \cong 122^{2}$
Pallet's entrance cost	3.5€ per pallet	521.5 €	514.5 €	427 €
Pallet's leaving cost	3.5€ per pallet	521.5 €	514.5 €	427 €
Subtotal – Fixed costs	**-**	**1 043 €**	**1 029 €**	**854 €**
Storage cost, per day	0.55€ per pallet per day	82 €/day	81 €/day	67 €/day

[1] It corresponded to the quantity of collected by-products for scenarios 1,2 and 3, respectively.
[2] The value was rounded up.

In addition to the costs presented in Table 25, there are other costs that must also be considered, such as: the cost of obtaining each pallet; the cost of obtaining the packaging material (of course, this cost depends on the required material); the cost of freezing; and, in cases where the goods cannot be palletized, the cost of using a container must be considered (250 € per container in the case of 40 feet containers and 150 € per container in the case of 20 feet containers). Because explicit values for these costs were not provided, unfortunately, these cannot be considered when calculating the final cost.

As it can be observed on the Table 25's last row, the storage cost varies according to the number of days during which the goods are stored. This variable, in the context of this work, is highly unpredictable, depending on how according to plan all the processes in between are able to be implemented. For instance, if the collection process takes longer than it was originally planned, the goods might have to be stored only for a few days. On the other hand, if the shipping day has to be rescheduled for some reason, the goods might have to be stored for a longer period than it was previously planned.

For the context of this dissertation, the author considered two scenarios: an optimist case scenario, where the goods are kept for just 2 days; and a pessimist case scenario, where the goods are stored for a week. The final costs of storage for both scenarios are presented in Table 26.

Table 26 - The total warehousing costs for the optimist and pessimist case scenarios (€)

	Optimist case scenario (2 days)			**Pessimist case scenario (7 days)**		
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Fixed costs	1 043	1 029	854	1 043	1 029	854
Cost of keeping the goods	164	162	134	574	566	470
Total warehousing cost	**1 207**	**1 191**	**988**	**1 617**	**1 595**	**1 324**

Then, regarding the transportation costs from the depot to the port or airport of departure, these depend on the following factors: the number of vehicles transporting the goods; the number of workers driving the trucks; the distance between the depot and the airport or port of departure and the existence of tolls to be paid. The calculation that must be made in order to calculate this cost is the following one:

$$Cost\ of\ moving\ the\ goods\ to\ the\ (air)port = number\ of\ trucks * (d * distance + H * time) + T \quad (26)$$

Regarding the number of trucks being driven for scenario 1 and 2, in order to be the most efficient as possible, four trucks must be used (three FTL, with a load of 32 tons, and one LTL, with a load of 4 420 Kgs). Then, the scalars *d* and *H* can be directly obtained from Table 23. Finally, the distance and time parameters can be easily obtained through Google Maps. For the case of the Lisbon airport, observe Figure 21.

In this case, because the distance is 11.3 Km, the duration is approximately 0.27 hours (equivalent to 16 minutes) and no tolls must be paid, the cost of moving the products from the depot to the Lisbon airport is **58 €**.

For the case of the Lisbon port, observe Figure 22. Because the distance is 19.7 Km, the duration is approximately 0.42 hours (equivalent to 25 minutes) and no tolls must be paid, the cost of moving the products from the depot to the port of Lisbon is **100 €**.

For scenario 3, the cost of moving the goods from the depot to the port or airport of departure is lower, because, for the quantity of by-products generated in this scenario, only three vehicles are needed: 2 FTL with a capacity of 32 tons and a LTL, with a load of 17 910 Kilograms. Therefore, the cost of moving the products from the depot to the Lisbon airport is **43 €** and the cost of moving the products from the depot to the port of Lisbon is **75 €.**

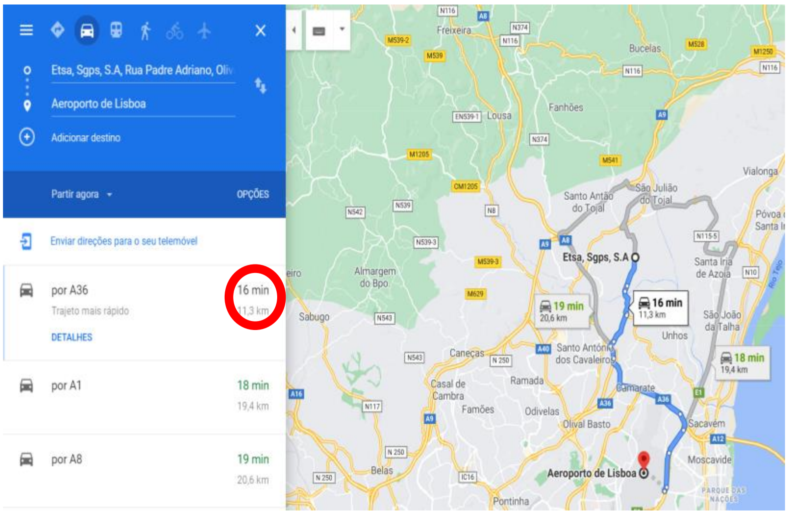


Figure 21 - Distance and duration of moving by truck from the depot to the Lisbon airport [138]

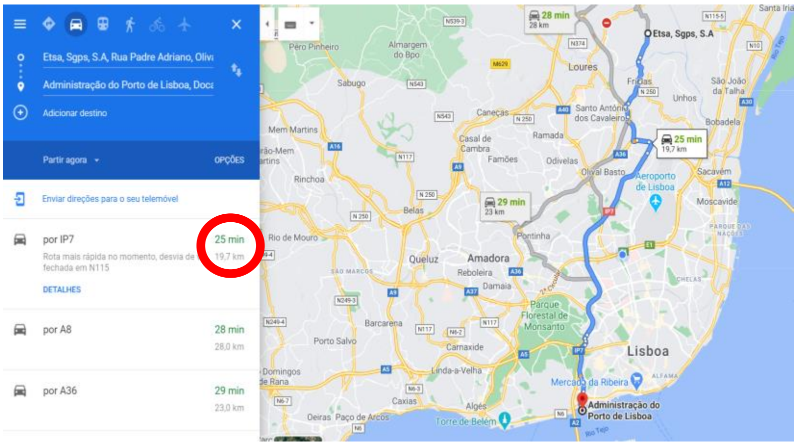


Figure 22 - Distance and duration of moving by truck from the depot to the port of Lisbon [139]

5.3 The second phase: the export of by-products

This section aims to demonstrate all the costs involved in the transportation of the collected by-products from Lisbon (Portugal) to Qingdao (China). As it was stated in section 4.2, two means of transportation are being considered: air freight and ocean/sea freight. The costs of air freight are presented in section 5.3.1 and the costs of ocean/sea freight are presented in section 5.3.2. For both cases, all the costs incurred in the process of transportation are demonstrated and explained, in the sense that all the incurred costs are presented, as well as the formula that was implemented so that the value of each cost could be obtained.

5.3.1 Air freight

The first step, weather it is the case of air cargo or ocean cargo, is to set up the conditions under which the goods are being moved. After doing some research related to how air cargo is usually moved, it was found that the Boeing 747-400F is an average sized plane that is often used to move air cargo and, therefore, the author used that plane as a reference in order to decide how the goods would be moved. In addition, the flight between the Lisbon airport and the Qingdao airport takes 13 hours [140]. The next question to be made was weather it would be necessary to arrange more than one flight in order to move the quantities generated in the three already mentioned scenarios (see section 5.2.1) of frozen meat products from Lisbon to Qingdao. By analysing reference [131], which presents the Boeing 747-400F's cargo structure, it was possible to find the load capacity of the plane, which is 112 900 Kgs, meaning that it was possible to move all the goods in just one flight. It is also known that there is space for 23 (244 x 317,5 x 300) cm pallets. Each pallet supports a M1-H reefer container. Each of these containers can support 6 800 Kgs of cargo and has 21.2 m^3 of intern cubic capacity. Regarding scenario 1, it is possible to distribute the 100 420 Kgs of goods for 14 full pallets and a semi-full pallet, giving a total of 15 utilized pallets. Regarding scenario 2, it is possible to distribute the 98 743 Kgs of goods for 14 full pallets and a semi-full pallet, too, thus being necessary a total of 15 utilized pallets. Finally, regarding scenario 3, it is possible to distribute the 81 910 Kgs of goods for exactly 12 full pallets. With that in mind, all the costs of moving all the goods from the Lisbon airport to the Qingdao airport were found and calculated. These are presented in Table 27.

Table 27 - Air freight costs (€)

Cost type	Cost name	Cost formula	Cost value			Reference
			Scenario 1	Scenario 2	Scenario 3	
Pre-carriage and carriage costs	HAWB[1] initial fixed costs	N. A.	18	18	18	[132]
	Fixed costs (including stamp duty), registration of airline, handling	N. A.	22	22	22	[132]
	Fuel surcharge	11% of base rate	22 093	21 723	18 020	[134]
	Pricing of air freight safety measures, fees owing to transporter	N. A.	20	20	20	[132]
	Insurance risk crisis (IRC)	N. A.	465	465	465	[132]
	Custom fees	3€ per HAWB	9	9	9	[132]
	Handling fee	10€ per MAWB[2]	30	30	30	[132]
	Export control system (ECS)[3]	7€ per ECS	21	21	21	[132]
	Outlay fees (DBC)	N. A.	54	54	54	[132]
	Processing fees	40€ + 0.052€ per Kg	5 262	5 175	4 299	[132]
	Cargo insurance	0.2% x 1.1 x Cargo Value	70	69	57	[128]
	Base rate	2€ per kg	200 841	197 485	163 820	Phone call with a Rangel employee[4]
Subtotal	**-**	**-**	**228 905**	**225 092**	**186 836**	**-**
Post-carriage costs	Terminal Charge	0.11€ per Kg	11 227	11 039	9 158	[133]
	D/O Fee	24.57€ per HAWB	74	74	74	
	Handling charge	24.57€ per HAWB	74	74	74	
	Sanitation	0.61€ per container	9	9	7	
	Warehouse In/Out	0.09€ per Kg	8 636	8 492	7 044	

	Forklift Fee	0.06 per Kg	6 045	5 944	4 931	
	Unloading Fee	0.49 per container	7	7	6	
	Quarantine Fee	6.14 per pallet	92	92	74	
	Freight Collect Surcharge	3% of the goods' value	959	943	782	
	Duty Handling Surcharge	3.69€ per HAWB	11	11	11	
	Holiday Surcharge	30.71€ per HAWB	92	92	92	
Subtotal	**-**	**-**	**27 226**	**26 777**	**22 252**	**-**
Total cost	**-**	**-**	**256 131**	**251 869**	**209 089**	**-**

[1] It stands for "house airway bill", which is issued by the freight forwarder, evidencing the terms and conditions of the carriage of goods as specified by the freight forwarder [135].
[2] It stands for "master airway bill", which must be issued and signed by the air cargo carrier, stating all the pre-agreed terms and conditions regarding the carriage of the goods from the shipper to the airport of destination [135].
[3] ECS stands for "electronic clearing system", which is a service provided by the bank when an electronic transfer from one bank account to another is needed.
[4] Rangel is a Portuguese shipping company that deals with air and ocean cargo.

As it can be observed in Table 27, the costs are divided into two main groups: the pre-carriage and carriage costs; and the post-carriage costs. The first group refers to all the costs and charges incurred at the airport of departure (the Lisbon airport, in this case) and during the goods' carriage, whereas the second group refers to all costs and charges incurred at the Qingdao airport, which, in this case, is the airport of destination. The first group accounts for the highest portion of the total cost (89.37% in the case of scenario 1, for example, while the post-carriage costs incurred in Qingdao account for 10.63%).

Just by observing the total cost of all presented scenarios, it is clear that this mode of transportation is too expensive, considering the total price for which the goods are being sold for (see Table 20). The base rate is the most expensive cost, accounting for approximately 78.41% of the total cost of export for the case of scenario 1, for instance. It is fair to say that this mode of transportation is so expensive because there are many charges which vary according to the weight being handled. In that sense, because many tonnes of goods are being exported, those charges turn out to be quite expensive (observe Terminal charge, for instance). Then, there are costs that vary according to the number of MAWB and HAWB being utilized (observe the Duty surcharge and the Handling fee, for example). In this context, it was considered that three HAWBs and MAWBs would be needed: one for the shipper, another for the carrier and another one for the consignee. Finally, there are the fixed costs, which, in spite of being quite high, they only account for a small portion of the total cost (observe the HAWB initial fixed costs).

A very important note that must always be kept in mind refers to the fact that the cost of exporting goods from one airport to another greatly depends on the season in which the goods are being moved, as well as on the demand for those goods at the place of destination in a given time. The cost of exporting goods in November will most likely be very different from the cost of moving those exact same goods, between the same countries, in March, for instance. There are so many external factors that influence all the costs stated in Table 27 that it is almost impossible to obtain the exact cost of moving goods from one airport to another, just by studying articles, books, reports or websites. The only way of obtaining an exact cost is by contacting an export agency (in this case, a Portuguese one). And even in those cases, a breakdown structure of the costs, like the one presented in Table 27, is not provided. The only value that is provided is an estimation of the total cost. Therefore, all the costs stated in the present section are just an estimate of the current total cost of exporting goods from Lisbon to Qingdao, which can be very different from the cost of moving the same products in the next month. Nevertheless, there are some time periods that must always be considered when planning the export of goods to China.

With that in mind, here are some 2020 dates which might have had influence on the costs incurred in the transportation process [136]:

- The first day and the last week of January due to the Chinese Spring Festival Holiday and the Chinese New Year day;
- The first week of April due to the Ching Ming Festival;
- The last week of June due to the Dragon Boat Festival Holiday;
- The first week of October due to the Mid-Autumn Festival and the Chinese National Day Holidays, as well as the last week, due to the Chung Yeung Festival.

5.3.2 Ocean/sea freight

As it was done with air freight, the first task that must be completed is to set out the conditions under which the goods are being exported. In the case of ocean/sea freight, it was decided that the goods would be exported in 40 feet reefer containers. Each of these containers has a payload capacity of 27700 Kgs and a cubic capacity of 59.3 m^3 [115]. For scenarios 1 and 2, the quantity of frozen meat products being transported, four 40 feet reefer containers are needed. However, for scenario 3, only three 40 feet reefer containers are needed. In addition, knowing that the distance between the Lisbon port and the Qingdao port is approximately 9 689 nautical miles via the Suez Canal and, assuming that the speed of the vessel is approximately 20 knots, it was concluded that the trip between both ports would take exactly 20 days and 4 hours [116]. With that in mind, all the costs of moving all the goods from the port of Lisbon to the port of Qingdao were searched and calculated. Table 28 presents such costs, only for scenario 1.

Table 28 - Ocean/sea freight costs (€) for scenario 1

Cost Type	Cost name	Cost formula	Base case scenario	Worst case scenario	Reference
Pre-carriage[1]	Packing charges	245€ per container	980	980	[117]
	Customs clearance	N. A	150	150	[119]
	wharfage	35.36€ per TEU	283	283	[120]
	Documentation charges	31€ per Bill of Lading	93	93	[117]
Carriage[1]	Ocean Freight Rate	3000€ per reefer container	12 000	12 000	Phone call with a Rangel employee[2]
	Bunker Adjustment Factor (BAF)	21.5€ per TEU	172	172	[121]
	International Security Port Surcharge (ISPS)	From 7.5€ to 9€ per container	30	36	[122]
	Bill of Lading Fee	N. A	430	430	[118]
	Export Service	15€ per container	60	60	[117]
	Emergency Bunker Surcharge (EBS)	378.4€ per ton	N. A.	37 999	[123]
	General Rate Increase (GRI)	4.9% of the base rate	588	588	[124]
	Piracy Surcharge[3]	36.98€ per TEU	296	296	[125]
	Peak Season Surcharge	516€ per container	N. A.	2 064	[117]

Post-carriage[1]	Currency Adjustment Factor (CAF)	5% of ocean freight rate	600	600	[126]
	Detention and Demurrage	86 € per container, per day	N. A.	N.A.	[127]
	Cargo insurance	0.2% * 1.1 * cargo value	70	70	[128]
	Commodity inspection	26€ per bill of lading	78	78	[93]
	Quarantine inspection fee	0.8 ‰ of total value of goods	26	26	[93]
	D/O (delivery order)	From 39€ to 45.5€ per bill of lading	117	137	[93]
	THC (terminal handling charge)	166.40€ per 40 feet reefer container	666	666	[93]
	Documentation fee	From 13€ to 52€ per BL	39	156	[93]
	Handling charge	From 26€ to 52€ per 40 feet reefer container	104	208	[93]
	Mechanical fee	From 13€ to 26€ per 40 feet container	52	104	[93]
	Customs declaration[4]	26€ per bill of lading	0	0	[93]
	Import tariffs[4]	1.5% of the price of the goods	0	0	[93]
	Port charge	65€ per 40 feet reefer container	260	260	[93]
	Refrigeration charge	78€ per 40 feet reefer container	312	312	[93]
	Inspection agency fees	39€ per bill of lading	117	117	[93]
	Handling charge	26€ per bill of lading	78	78	[93]
	Storage charges, demurrage charges, container maintenance fee, cleaning fee	19,5€ per container	78	78	[93,117]
Total	**-**	**-**	**17 678**	**58 040**	**-**

[1] The pre-carriage and carriage costs were taken from Table 19. The pre-carriages costs were taken from Table 20

[2] Rangel is a Portuguese shipping company that deals with air and ocean cargo

[3] This charge must be paid every time a vessel goes through the Suez Canal

[4] Incoterm – DAT

As it can be observed in Table 28, some of the costs were put directly into the Table, without any underlying formula, as these costs were read and imported from their respective references (observe, for instance, the customs clearance cost). Other costs contain underlying formulas that depend on variables which deserve some explanation. For instance, a variable that is often used in order to calculate certain costs is the TEU (observe, for example, the case of wharfage). This is a size variable which is equivalent to the size of a 20 feet container [129]. Therefore, since the goods are being exported

in four 40 feet containers in scenarios 1 and 2, 8 TEUs were considered in the context of those scenarios. For scenario 3, however, by using the same logic, because three 40 feet reefer containers are needed, 6 TEUs are being considered. In addition, an expression that is frequently used in Table 28 is "per bill of lading", as it happens in the case of documentation charges. In the context of this dissertation, it was considered that, at least, three bills of lading would be necessary: one for the exporter, one for the importer and a third one for the shipping which moves the goods from the port of departure to the port of destination [130]. Also, the value of goods, which is used, for instance, in the insurance cost, is the total price presented in Table 20.
By analysing again Table 28, one must note that two scenarios related to the magnitude of ocean/sea freight costs are being studied: a **base case scenario** and a **worst-case scenario**. This distinction in scenarios was made so that the reader can understand how greatly the total cost can vary if procedures do not run according to what was previously planned. The existent variations in prices mainly occur due to fuel price fluctuations and demand variability. For some of the costs presented in Table 28 (observe, for example, the packing charges, presented in the pre-carriage costs), they do not differ from both scenarios, as their values usually do not vary seasonally. Then, there are the charges which usually vary within a range (mechanical fee, in the post-carriage costs). For those cases, the highest value within the range was attributed to the worst-case scenarios, whereas the lowest one was given to the base case scenario. Also, there are costs which were only attributed to the worst-case scenarios (for example, the peak season surcharge). These costs were exclusively attributed to the worst-case scenario because the exporter, when planning the moving of the goods (in the base case scenario), must pay special attention and avoid seasons in which the overall costs of exporting goods are much higher. Then, there are costs which were not attributed to any of the presented scenarios, as these costs are based on events whose repercussions are too unpredictable, like the case of detention and demurrage charges. However, their values must always be kept in mind as well as their effects on the exportation process as a whole. Finally, there are costs that are not applied in the specific context of the present dissertation, due to the chosen incoterm – DAT (observe customs declaration).

Just by comparing the final cost of the two scenarios, it is quite noticeable how much it can change if the export occurs in different time periods. Just by looking at the worst-case scenario, note that the final cost of moving the products from Portugal to China, without accounting for all the other costs of collecting and storing the goods that are incurred before the start of the exporting procedure, is already higher than the value of the goods being sold (observe Table 20). Some of the post-carriage costs vary from one scenario to another, but undoubtably the Peak Season Surcharge and the Emergency Bunker Surcharge (EBS) are the ones that make the most difference, accounting for approximately 99.26% of the difference between the two scenarios under study, for scenario 1. Of course, just as expected, the surcharges are highly based on the variability of demand and fuel prices.

As it was already stated in section 5.3.1, the cost of exporting good from one port to another depends substantially on the time period under which the goods are being moved, as well as on the demand for those goods at the place of destination at that same time period. The cost of exporting goods in November will most likely be very different from the cost of moving those exact same goods, between the exact same ports, in any other month of the year. Again, the only way of obtaining an exact cost is by contacting a Portuguese sea cargo shipping company. And even in those cases, a breakdown structure of the costs, like the one presented in Table 28, is not provided by that agency. The only value that is provided is an estimation of the total cost. Thus, all the costs stated in the present and in the previous section are just an estimate of the current total cost of exporting goods from Lisbon to Qingdao, which can be very different from the cost of moving the same products in the following months. The dates which might have influence on the costs incurred in the transportation process were already stated at the end of section 5.3.1.

Finally, Table 29 demonstrates a comparison between the ocean/sea freight costs of the three scenarios demonstrated in 5.2.1. In Table 29, only the costs which vary according to the number of needed containers, quantity or value of all by-products being transported are presented. In addition, the last row of such Table demonstrates the final cost of ocean/sea freight for the three scenarios.

As one can understand from Table 29, for the base case and for the worst-case scenarios, the final costs of transporting ocean/sea freight are very similar in scenarios 1 and 2, as there are very few costs that vary according to weight or value. Because in scenarios 1 and 2 the same number of containers is needed, the total cost of ocean/sea freight do not vary much. However, when comparing scenario 3 with the other two scenarios, the cost of ocean/sea freight drops to 13 540 € in the case of the base case scenario and to 46 341 € in the case of the worst-case scenario. This bigger variation in cost is mostly due to the fact that in the latter scenario, only three containers are used.

Table 29 - Ocean/sea freight costs for the three scenarios (€)

Cost type	Cost name	Cost Base case scenario			Cost Worst case scenario		
		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Pre-carriage	Packing charges	980	980	735	980	980	735
	wharfage	283	283	212	283	283	212
Carriage	Ocean Freight Rate	12 000	12 000	9 000	12 000	12 000	9000
	BAF	172	172	129	172	172	129
	ISPS	30	30	22.5	36	30	27
	Export Service	60	60	45	60	60	45
	EBS	N. A.	N. A.	N. A.	37 999	37364	30 995
	GRI	588	588	441	588	588	441
	Piracy Surcharge	296	296	222	296	296	223
	Peak Season Surcharge	N. A.	N. A.	N. A.	2 064	2 064	1548
	CAF	600	600	450	600	600	450
	Cargo insurance	70	69	57	70	69	57
Post-carriage	Quarantine inspection fee	26	26	21	26	25	21
	THC	666	666	499	666	666	499
	Handling charge	104	104	78	208	208	156
	Mechanical fee	52	52	39	104	104	78
	Port charge	260	260	195	260	260	195
	Refrigeration charge	312	312	234	312	312	234
	Storage charges, demurrage charges, container maintenance fee, cleaning fee	78	78	59	78	78	59
	Total cost[1]	**17 678**	**17 677**	**13 540**	**58 040**	**57 403**	**46 341**

[1] Note that the total cost is not the sum of the remaining costs presented in Table 31. Instead, it is the sum of all costs presented in Table 30, applied to each scenario.

5.4 Cost/Benefit analysis

The goal of this section is to balance all the costs discussed throughout this entire chapter with the revenues generated by the sale of the exported by-products (mentioned in section 5.1). By balancing such values, the profits generated in each possible scenario can be obtained. In Table 30, the profit demonstration for the case of air freight can be observed. The scenarios presented at the top of the table represent the ones discussed in section 5.2.2, where the main warehousing costs are studied. In addition, in the row below, the three scenarios presented in section 5.1 are presented as well, so that the resulting profits of all scenarios can be properly demonstrated and compared.

Table 30 – Profit demonstration for the case of air freight (€)

	Optimist case scenario	Pessimist case scenario	Optimist case scenario	Pessimist case scenario	Optimist case scenario	Pessimist case scenario
	Scenario 1		**Scenario 2**		**Scenario 3**	
Revenues	**31 954**		**31 420**		**26 066**	
Collection cost	3 182		2913		879	
Warehousing costs	1 207	1 617	1 191	1 595	988	1 328
Moving the goods to the Lisbon airport	58		58		43	
Subtotal – Domestic costs	**4 447**	**4 856**	**4 162**	**4 566**	**1 911**	**2 251**
Air freight costs	256 131		251 869		209 089	
Total costs	**260 578**	**260 987**	**256 031**	**256 435**	**211 000**	**211 339**
Profit	**-228 623**	**-229 033**	**-224 611**	**-225 015**	**-184 934**	**-185 274**

As it was expected, the cost of moving the goods under study by plane are too high when compared to their value, that is, to their generated revenues. The air freight costs, alone, are already much higher than the expected generated revenues. As a result, the generated profits are negative for all the scenarios which were studied in the context of the present dissertation. Such results show that air freight is not a viable option when moving pig meat by products from Lisbon to Qingdao.

On the other hand, Table 31 exhibits the profit demonstration for the case of ocean/sea freight. Once again, at the top of the table, the two scenarios related to the warehousing costs are presented. Then, in the row below, the three scenarios presented in the first section of the present chapter are presented as well. Finally, on the left side of the table, the two scenarios presented in section 5.3.2, the one where all the ocean/sea freight costs are demonstrated, are presented. This way, the profits resulting from all scenarios can be properly demonstrated and compared.

Unexpectedly, scenario 3 proved to be more profitable than the other two scenarios, for all scenarios related to warehousing costs and sea freight costs. There is a plausible explanation for that. Although the increase regarding the quantity of exported by-products results in an increase in expected revenues, such revenue increase is not high enough to offset the resulting increase in costs, due to the added trucks (for the collection process) and to the added 40 feet reefer container (in the exporting process). Thus, it is more profitable to export three almost full containers than to export four (three full containers and a less-than-full container). Additionally, it is proved that it is better to exclusively move full containers than to move a less-than-full container. As it can be again observed in Table 28, most of the costs depend on the number of containers being moved and not on the actual weight being moved. In addition, it is known that, for scenarios 1 and 2, the same number of containers are needed (four) to transport the required quantity of by-products. That results in very little variation between the ocean/sea freight costs of those two scenarios, although there is a difference of 1 677 Kgs in weight being moved between scenarios 1 and 2. On the other hand, the generated revenues directly vary with the quantity of goods being traded, thus being the variance in revenues much higher than the variance in ocean/sea freight costs. This results in a lower profit for scenarios 2 when compared to scenario 1. This may lead one to conclude that the fuller the containers being transported, the higher the final profit, if only the ocean/sea freight costs are being considered, since revenues grow more according to the weight being transported than ocean/sea freight costs.

Table 31 - Profit demonstration for the case of ocean/sea freight

		Optimist case scenario	Pessimist case scenario	Optimist case scenario	Pessimist case scenario	Optimist case scenario	Pessimist case scenario
Both scenarios		Scenario 1		Scenario 2		Scenario 3	
	Revenue	**31 954**		**31 420**		**26 066**	
	Collection cost	3 182		2 913		879	
	Warehousing costs	1 207	1 617	1 191	1595	988	1 324
	Moving the goods to the port of Lisbon	100		100		75	
	Subtotal – Domestic costs	**4 489**	**4 898**	**4 204**	**4 608**	**1 943**	**2 278**
Base case Scenario	Ocean/sea freight costs	17 678		17 677		13 540	
	Total costs	**22 167**	**22 577**	**21 880**	**22 285**	**15 483**	**15 819**
	Profit	**9 788**	**9 378**	**9 539**	**9 135**	**10 583**	**10 247**
Worst case scenario	Ocean/sea freight costs	58 040		57 403		46 341	
	Total costs	**62 528**	**62 938**	**61 607**	**62 011**	**48 284**	**48 619**
	Profit	**-30 574**	**-30 984**	**-30 187**	**-30 592**	**-22 218**	**-22 554**

Unlike the case of air freight, there are some scenarios which generate positive profits. All profits resulting from the base case scenario are positive, regardless of any other scenarios related to warehousing costs or quantity being transported (scenarios 1,2 and 3). Naturally, the highest profit corresponds to the base case scenario combined with the optimist case scenario. In the case of scenario 3 (the one that resulted in the highest profits) the profit is **10 583 €**. This result shows that exporting pork by-products by ocean and sea might be a viable option, financially. On the other hand, the worst-case scenario demonstrates how profits can drop if the exporting procedure is not properly planned or if unpredictable events which increase the shipping costs occur, thus generating negative profits. For the worst-case scenario, all profits are negative, regardless of any scenario related to warehousing costs or volume being exported. Naturally, this is because of the big difference between the ocean/sea freight costs in the base case scenario and in the worst-case scenario.

Table 32 demonstrates the duration of all the processes studied throughout this chapter. As one can immediately observe, the air freight duration is much shorter than the ocean/sea freight duration. The shortest duration refers to the movement of air cargo quantity stated in scenario 3 under the optimist case scenario, whereas the longest scenario refers to the movement of ocean cargo quantity stated in scenario 2 under the pessimist case scenario.

Table 32 - Duration of all processes

Storage scenario		Ocean/sea freight			Air freight		
		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 1**	**Scenario 2**	**Scenario 3**
	Collection	15h20	15h30	08h00	15h20	15h30	8h00
Optimist case scenario	Storage	2 days					
Pessimist case scenario	Storage	7 days					
	Take to Port/Airport	25 minutes			16 minutes		
	Foreign transit time	20 days 04h00			13h00		
Optimist case scenario	**Total duration**	**22 days 19h45**	**22 days 19h55**	**22 days 12h25**	**3 days 04h36**	**3 days 04h46**	**2 days 21h16**
Pessimist case scenario	**Total duration**	**27 days 19h45**	**27 days 19h55**	**27 days 12h25**	**8 days 04h36**	**8 days 04h46**	**7 days 21h16**

An important note refers to the fact that none of the durations stated in Table 32 imposes a problem due to the perishable nature of the products being exported. This is because, as it can be observed in section 4.2.3, frozen meat by-products have a practical storage life of 4 months (approximately equivalent to 120 days), which is much larger duration than the ones presented in the Table. Therefore, as long as the temperature of the goods is properly controlled throughout their entire practical storage life, there is more than enough time for the products to be exported and then commercialized.

5.5 Sensitivity analysis regarding the frequency of collection

As it has been concluded from the previous sections presented in this chapter, the profits resulting from the export of meat by-products can significantly vary according to the quantity being exported, especially when the number of containers being moved changes. The main point is that the different quantities collected by the exporter result in different exporting costs and revenues, thus resulting in different profits for the exporter. As it was concluded from section 5.4, scenario 3, which includes the movement of three containers, lead to higher profits when compared to the other two scenarios, which include the movement of four containers. This may lead to the question of whether it is more profitable to move an even lower number of containers, that is, two or even one single container.

With that in mind, a sensitive analysis regarding the frequency of collection was performed. The main purpose is to study how the frequency of collection, which leads to different numbers of containers being moved, impacts the exporting costs and revenues generated by the exporter. From the three scenarios which were presented in section 5.1 (scenarios 1,2 and 3), scenario 3 was the chosen one for the sensitive analysis, simply because that is the one that leads the exporter to the highest profit. In this case, three options were considered: the goods are collected after a working day; the collection is done after two working days and all by-products are collected after three working days. The first option leads to the movement of 27 303 Kgs of pork by-products, which fit in one 40 feet reefer container; the second option leads to the movement of 54 607 Kgs of goods, which fit in two containers; finally, the third option, as it was already studied in the previous sections, leads to the movement of 81 910 Kgs, thus fitting in three containers. Figure 23 presents the resulting costs incurred by the exporter, as well as the generated revenues and profits, according to the frequency of collection. In this case, the costs spent by the exporter were obtained by applying the same methodology as the one that was explained in chapter four and throughout the present chapter.

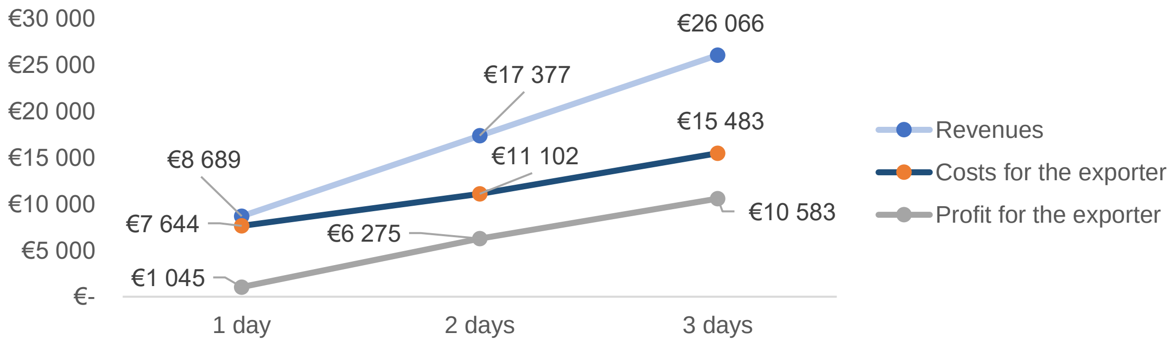


Figure 23 - Costs spent by the exporter, according to the frequency of collection

As it can be concluded from Figure 23, although the exporting costs increase with larger storage durations, the resulting profit also increases. Therefore, the exporter prefers the collection process to be performed after three days, leading to the export of three containers. However, one might ask what would happen if one, two, three or four completely full containers were exported. That is because, as it was concluded in section 5.4, by comparing scenarios 1 and 2, fuller containers lead to higher profits.

5.6 Chapter conclusions

The main objective of this chapter was to implement the methodology proposed in chapter 4. First, all domestic costs were calculated and demonstrated. The domestic costs are composed by the collection costs, the warehousing costs, and the costs of moving the collected goods to the airport or port of departure. Secondly, like in the methodology's chapter, the costs of moving the goods from Lisbon (Portugal) to Qingdao (China) by ship and by plane were studied. In that sense, these costs were calculated and demonstrated. Then, a cost/benefit analysis was performed in order to compare the total costs of exporting the collected by-products by ship and by plane with the revenues that result from the sale of those same by-products. The chapter ends with a sensitivity analysis regarding the frequency of collection performed by the exporter and the resulting revenues, costs and profits.

First, the collection costs were calculated and demonstrated for the three scenarios. As it was already stated, they were calculated by implementing the mathematical model presented in the Methodology's chapter in GAMS. Naturally **the resulting costs of scenario 1 were the highest ones and the ones of scenario 3 were the lowest**, because more slaughterhouses are considered in scenario 1 and, therefore, the travelled distance is much higher, which critically affects the total collection cost.

Secondly, the warehousing costs were demonstrated and explained. **As one would expect, the highest warehousing costs belong to the scenario 1 and the lowest ones belong to scenario 3**. Then, the costs of moving the goods to the port or airport of Lisbon were calculated and demonstrated. It was concluded that, in order to move the goods from the depot to the port of departure, the costs would be the same for scenarios 1 and 2, because four trucks were needed for both scenarios. However,

the costs of moving the quantities generated in scenario 3 were lower, since, in that case, only three trucks were needed. In addition, it was concluded that **the costs of moving the goods to the airport would be lower than the costs of moving them to the port of Lisbon**, since the airport is closer to the depot.

Thirdly, the air freight costs were demonstrated. For this case, the main conclusion to take is that **the cost of moving the collected meat by-products by plane from Lisbon to Qingdao are just too expensive**. Just the base rate alone is 2 € per kilogram, meaning that this parcel of the final cost of airfreight account for more than two hundred thousand euros for any of the three previously presented scenarios.

Then, regarding the ocean/sea freight costs, **the costs resulting from the worst-case scenario are much higher than the ones resulting from the base case scenario**. One very important note that must be considered consists on the fact most of the ocean/sea freight costs depend on the number of containers being moved, and not on the actual weight. Therefore, because for scenarios 1 and 2 four containers are needed, there are only little variations between the resulting ocean/sea freight costs of these two scenarios. However, for scenario 3, only three containers were needed, meaning that the resulting ocean/sea freight costs were considerably lower for this scenario. One last important note was that, by observing the ocean/sea freight costs of scenarios 1 and 2, one could conclude that the fuller the containers, the more “cost-effective” the exporting process will be, since the cost does not increase that much and the revenues resulting from the sale of the exported products do.

Then, a cost/benefit analysis was applied, where the domestic and international costs were summed for all the studied scenarios and then compared to their respective revenues, so that the profits of all studied scenarios could be obtained and compared. Herein, the main conclusion to take is that, regarding the exportation process, the only financially viable scenario is the sea/ocean freight costs’ **base case scenario**. In that scenario, all profits are positive and above 9 000 €, where, surprisingly, the most profitable scenario proved to be scenario 3. Additionally, for the same scenario, the profit that resulted from scenario 1 proved to be higher than scenario 2’s. This proves that, when transporting a given number of containers, it is financially better to move exclusively full containers, since these are the ones that lead to the highest profit. On the other hand, however, all other scenarios related with the exporting costs (the air freight costs and the worst-case scenario from the ocean/sea freight costs) are all negative, thus proving not to be financially viable options.

Finally, the chapter ends with a sensitivity analysis regarding the relationship between the costs spent by the exporter and the frequency of collection of pig meat by-products from the studied slaughterhouses. As it was expected, the lower the frequency of collection, the higher the resulting costs and revenues for the exporter. However, the most relevant result refers to the fact that the profit also increased with lower frequencies of collection, meaning that the best option for the exporter is to collect the goods every three working days (the lowest frequency of collection).

6. Conclusions, limitations and future work suggestions

The main motivation for this dissertation was to highlight the need for reducing meat waste, or, at least, reducing the meat quantity that goes to improper destinations. Because pig meat proved to be the most wasted meat, it was decided that pig meat would become the focus of this work. The main objective throughout the entire thesis was, therefore, to search for opportunities to reduce the quantity of wasted pig meat and add value to pig meat that otherwise would be unsold, wasted or lost.

In the literature review chapter, many technological applications for meat by-products were discussed. It was proven that, if all animal by-products are considered, those can comprise a wide variety of scientific fields, including nutrition food safety, medicine and pharmaceutical applications, cosmetics, energy generation, fertilization, chemical applications. Therefore, it was concluded that the meat sector should use more science and innovation to add value to animal by-products far beyond their usual profitability. Since one of the specific problems under study in the context of the present dissertation was the collection of by-products, Vehicle Routing Problems and, more specifically, waste collection problems were also studied in this chapter.

However, the presented methodology did not provide any new technologic nor scientific innovation insights towards meat by-products. Instead, the methodology provided by the author presented a new market opportunity for pig meat by-products. More specifically, the goal of the present dissertation was to explore the possibility of exporting pork by-products to China, a country where such by-products are surely valued, thus not being wasted. China was chosen to be the importing country for the context of this dissertation because of all the features of the Chinese variety meats' market that makes it such a promising opportunity for all the stakeholders involved. First, it is much less costly for Chinese pig meat industry entities to import directly from other countries than to produce domestic pig meat. Therefore, with the rise of domestic pork prices, the less expensive foreign pork becomes more competitive in the Chinese market. In addition, the EU countries and Chinese consumers have complementary tastes that encourage pork trade between both groups. European consumers prefer muscle meats, while Chinese consumers prefer offal and variety meats that have low value in the EU countries. By analyzing Figure 20 again, the fact that the price of most variety meats is much higher in China than in other countries is quite noticeable. This idea was, therefore, considered to be a win-win situation for all the stakeholders involved. The exporting company wins because it has found a new business opportunity that could be beneficial in financial terms. The importer wins by finding a supplier that provides a type of product that is highly consumed in the importing country, at a potentially lower price. The citizens of the importing country win because there is now a greater offer for a type of product that is highly consumed. The citizens of the exporting country win because a large volume of wasted meat, which could harm the country financially, environmentally and socially, has been avoided.

The main conclusion to take regarding the results of the methodology imposed by the author is that, under certain external scenarios which cannot be controlled, exporting pig meat by products from Lisbon to Qingdao by ship can be a financially viable option. For the purpose of this work, those external conditions that positively affect the overall profit are presented by the base case scenario, combined with any scenario related to warehousing costs and quantity that is being exported. Considering the scenarios presented throughout the entire chapter, the highest profit one can get is 10 583 €, which is generated by scenario 3, which is also the one that generates the lowest revenues. This result is highly interesting as it contradicts the idea that states that one must export the highest possible quantity of by-products in order to generate higher revenues and, therefore, higher profits. As it was proven in this dissertation, that idea is simply wrong because of the fact that most of the ocean freight costs vary according to the number of containers being exported, and not as much according to the weight that is being moved. As one decides to export, for instance, three full containers and an extra almost empty container instead of just three full containers, one must pay for a much higher cost that is caused by the need of an extra container. Sometimes, the increase in cost might be high enough to offset the increase in revenues, which leads to lower profits. This reasoning is fully displayed in this work when the resulting profits that are generated by scenarios 1, 2 and 3 are compared. This is why the profit of scenario 3 is higher than the one of scenario 1, which, in turn, is higher than the profit of scenario 2.

As it can be again observed it Table 31, it is not always guaranteed that ocean/sea transportation is a lucrative mean of transportation. Under certain circumstances, which are presented by the worst-case scenario, ocean/sea freight costs can increase to a point where it is not financially beneficial to export the same goods by ship anymore. This distinction regarding the costs of ocean/sea freight was made in order explain how, even when planning on exporting products by using an apparently mean of transportation, one might be deceived by numerous external factors that might not be initially considered, that negatively affect the costs. These factors are often related with fuel surcharges, demand variations, but they can also be caused by bad planning. Therefore, when exporting goods, one must always be cautious and aware of the surrounding environment. Regarding air freight, it turned out to be the least financially viable option for exporting meat by-products from Portugal to China, despite being the fastest mean of transportation.

Regarding the sensitivity analysis, which was performed in section 5.5, it was concluded that it is more beneficial to export the goods after these are stored in the slaughterhouses for three working days, as this is the frequency of collection that leads to the highest profit.

6.1 Limitations

Unfortunately, there are some limitations associated with the methodology developed by the author. The main goal of this section is to present those limitations so that they can be analysed and, hopefully, corrected or mitigated in the future.

Firstly, although the proposed methodology might prevent high volumes of meat by-products' waste since it provides a purpose for a high volume of generated by-products, it does not have any effect on meat that have already been considered as unconsumable or unconsumed. Therefore, the methodology presented in this dissertation does not make an impact on wasted meat products, but it might constitute a very meaningful measure to prevent more pig meat waste.

Secondly, the presented methodology did not provide any of the innovative technologic nor scientific insights towards meat by-products that were mentioned in the literature review's chapter. Nevertheless, the methodology provides an innovative procedure that adds value to animal by-products far beyond their usual profitability.

In addition, there are some limitations to the model suggested and then implemented by the author. Regarding the first phase, more specifically the collection process, by observing annex 10, the presented relative gaps related to the model that was implemented in GAMS are simply too high, even though the computational effort was four hours. Such results might have occurred due to the fact that the implemented model was "too heavy" for the computer that was used (the author's personal computer) to obtain better results in just four hours.

Then, still regarding the first phase, all the costs presented throughout this work were obtained from reports, articles, websites and other documents, instead of direct conversations through meetings with specialists who could have given the author more accurate values for the costs presented and, more importantly, that could have given additional costs that were not even considered in this work. For this reason, the final costs might be inaccurate. For instance, one very important cost that was not considered in this work due to lack of information provided by articles, reports or websites is the freezing cost, when storing meat. This cost, if considered, would surely increase the final warehousing costs presented in the previous chapter. However, some of the presented costs, such as the warehousing costs and all the base rates related to the presented exporting costs, were provided by specialists who, although did not provide the exact cost, provided relatively accurate cost estimations which helped the author calculating the final cost in a more precise way

There is a specific cost that is highly relevant but was not considered in this work due to its unpredictable nature, which is the cost of purchasing the goods from the slaughterhouses. Although a collaboration framework was studied throughout this dissertation, the goods are not always provided for free. Actually, the goods can be given for free or sold for a price. The possibility of providing by-products for free or the price at which they are sold depend on each situation, thus being highly unpredictable. Therefore, the assumption that the goods are provided for free can be inaccurate. Such inaccuracy may result in relevant variations regarding the resulting profits. Hence, this problem can only be solved through direct dialogue and negotiations between the exporter and each slaughterhouse.

Then, there are some limitations regarding the ocean/sea freight costs and the airfreight costs as well. As it was already stated, the cost of exporting good from one port or airport to another greatly depends on the season in which the goods are being moved, as well as on the demand for those goods at the place of destination in a given time. Therefore, the cost of exporting goods which were presented in this dissertation will most likely be very different from the cost of moving those exact same goods, between the same ports, in any other month. There are so many external factors that influence all the export costs that it is almost impossible to obtain the exact cost of moving goods from one airport to another, just by studying articles, books, reports, or websites. The only way of obtaining an exact cost is by contacting an export agency (in this case, a Portuguese one). And even in those cases, a breakdown structure of the costs is generally not provided. The only value that is provided is an estimation of the total cost. Hence, the costs presented throughout this work are just an estimate of the current total cost of exporting goods from Lisbon to Qingdao. The exporter must always pay attention to the current demand and to current fuel price fluctuations before making any exporting decisions.

Additionally, there is another type of cost that is related to the exporting process, which was not considered in this dissertation, that is the inventory cost. This cost can highly affect the total exporting, especially in the case of ocean/sea freight, since that is the slowest mean of transportation. That is why air freight, in the case of high-value products that have a short life cycle, might be a viable option.

Finally, one can notice that the prices which were used in order to obtain the value of the exported by-products (see Table 18), the prices are from May 20th of 2010. Hence, more current values must be used in order to obtain the value of the traded by-products.

6.2 Future work suggestions

In the context of preventing and avoiding meat waste, there will always be future work suggestions. New scientific and technological insights will always arise. The important feature to keep in mind is that those insights can add more value and financial stability to meat products being wasted.

Regarding the methodology applied in this work, there are some future work suggestions that must be stated. Firstly, as was pointed out in section 6.1, there is a clear limitation related with the GAMS model that was implemented in the collection process, which is the fact that the presented relative gaps are just too high (see annex 10). With that in mind, one might suggest using a computer that can tolerate higher computational efforts, in order to obtain smaller gaps and, therefore, better results.

Then, one can suggest all the costs involved in the processes of collecting, storing and exporting by-products to China, as well as the resulting revenues, to be obtained through direct communication with specialists, who are able to provide accurate costs, so that a more reliable estimation of the final profit can be obtained.

Thirdly, more specifically related to the export process, one can explore what would happen if three and four completely full 40 feet containers were transported, that is, 83 100 Kgs and 110 800 Kgs of frozen meat products, respectively. This is because, as it was explained in section 5.4, the fuller the containers, the higher the resulting profit. In addition, it would be really important to compare the profits resulting from the export of four full containers with the ones from three full containers, in order to understand if the increase in revenues is high enough to offset the increase in costs (resulting from adding trucks, workers and containers to the whole process) resulting from the difference in quantity of the goods being exported. To go even further, by observing Table 22, one can see that the kidney is the most expensive by-product in China. Hence, one could suggest the export of a higher portion of (or even exclusively) kidneys, in order to obtain a higher profit.

The main point is that, as the author initially suspected, the idea of exporting pig meat by-products from Portugal to China can be seen as a promising opportunity to all stakeholders involved. The work presented so far may be seen as an estimate of how the exporting process might proceed and, although a deeper and more accurate analysis is needed, it is still a good starting point, as it provides the main insights regarding the conditions and costs involved in the entire exporting process.

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[140] - Flight Time and Distance Calculator. https://airplanemanager.com/flightcalculator.aspx. Accessed: 2020-12-04

Annexes

Annex 1 – All the studied slaughterhouses, with their respective addresses and production typologies

Short designation	Designation	Address	Does it deal with piglets?	Does it deal with average sized pigs?
s0	Depot - ETSA's collection point	Rua Padre Adriano, Olivais De Machio, Santo Antão Do Tojal, Lisboa	0	0
s1	H, M, CANEIRA, LDA	Rua das Comeiras, nº 9, Negrais ,2715-321 ,Almargem do Bispo	1	0
s2	MANUEL SIMÕES ROSA, LDA	Rua do Moinho, 14-Negrais ,2715-332 ,Negrais-Almargem do Bispo	1	0
s3	Leitões de Negrais, Lda	Av, General Barnabé António Ferreira, nº 113 ,2715-315 ,Negrais-Alm	1	0
s4	SANTACARNES - COMÉRCIO E INDÚSTRI	Rua do Matadouro Regional-Zona Industrial de Santarém ,2005-002	1	1
s5	CARMONTI – Indústria de Carnes do Monti	Estrada do Seixalinho, s/n ,2870-491 ,Montijo	0	1
s6	CASO – Centro de Abate de Suínos do Oes	Quinta do Munhoz ,2665-314 ,Milharado	0	1
s7	VALSABOR, S,A,	Rua da Cooperativa ,2025-254 ,Alcanede	1	1
s8	GRAZICAR-Comércio e Indústria de Carnes	Alguber, Gouxaria ,2550-017 ,Alguber	0	1
s9	INDÚSTRIA & COMÉRCIO DE CARNES DA	R, da Azenha, Pinheiro de Loures ,2670-398 ,Horta-Nova-Lagariça	0	1
s10	MARGARIDO & MARGARIDO, LDA	Zona Industrial de Alferrarede - Olho de Boi ,2200-052 ,Alferrarede	0	1
s11	SICASAL- INDUSTRIA E COMÉRCIO DE C	Rua da Indústria s/ nº, Vila Franca do Rosário ,2669-001 ,Vila Franca	0	1
s12	LEOCARNES-Comércio e Indústria de Carn	Estrada Real-Porto Alto, nº 165 ,2135-104 ,Porto Alto-Samora Correia	0	1
s13	RAPORAL, S,A,	Pau Queimado, Afonsoeiro ,2870-803 ,Montijo	1	1
s14	Ribasabores, Indústria de Carnes, Lda,,	Zona Industrial de Tomar- Santa Cita ,2305-127 ,Madalena	0	1
s15	HENRIQUE BENTO, LDA	Bêco da Pinta, 9-Morgado ,2625-618 ,Morgado-Vialonga	0	1
s16	TRICAR-Empresa Industrial de Carnes, Ld	EN 242, Pinhal do Rei, Vale do Carro, São Martinho do Porto ,2460-5	0	1
s17	MERCARNE-Comércio e Indústria de Carne	R, do Casal Modorno, 10-Perna de Pau, Sapataria ,2590-424 ,Sobral	0	1
s18	Quintino dos Leitões, Lda,	Avenida General Barnabé António Ferreira, nº 151 ,2715-315 ,Negrais	1	0
s19	A,F,J,P,- Comércio de Leitões de Negrais,	Rua dos Serrados, 26-Negrais ,2715-346 ,Negrais	1	0
s20	Instituto Nacional de Investigação Veteriná	Estação Zootécnica Nacional, Fonte Boa ,2005-048 ,VALE DE SANT	0	1
s21	MATISILVA - CARNES, LDA,	Zona Industrial de Condeixa-a-Nova, Lote 17 ,3150-194 ,Sebal Grand	1	1
s22	LEITÃO DOURADO-Abate, Transf, e Comér	Rua da Boça, 686-Casal do Pilha-Milagres ,2415-014 ,LEIRIA	1	0
s23	CASA DE SARMENTO, S,A,	Restaurante Meta dos Leitões-E,N, 1-Sernadelo ,3050-382 ,Sernadel	1	0
s24	SOCIEDADE HOTELEIRA PEDRO DOS LEI	E,N, 1-Sernadelo ,3050-382 ,Mealhada	1	0
s25	RESTAURANTE CASA ABÍLIO MARQUES,	Rua da Capela, 182-Bonsucesso ,3810-383 ,Aveiro	1	0
s26	AUGUSTO VIRGÍLIO DE SOUSA & FILHOS	EN 1, nº 118, Peneireiro-Aguim, 3780-624 ,Anadia	1	0
s27	FILARVINA, Lda,	Zona Industrial de Febres, Lotes 15 e 16-Febres ,3060-345 ,Febres	1	0
s28	MACTRIL - MATADOURO DO CABRIL, LDA	Castelo Velho ,3270-129 ,Pedrógão Grande	1	1
s29	INCARPO - INDUSTRIA E COMÉRCIO DE C	Zona Industrial de Condeixa, Lote 12 Sebal ,3150-194 ,Sebal - Conde	0	1
s30	MAPICENTRO-Sociedade de Abate, Comér	Ponte das Mestras, Barosa ,2401-975 ,Leiria	0	1
s31	FRESBEIRA -Indústria de Carnes, Lda,	Zona Industrial de S, Miguel de Poiares, Apartado 113 ,3350-214 ,Vil	1	1
s32	OVIGER-PRODUÇÃO, TRANF, COMÉRCIO	ESTRADA S, DOMINGOS ,6005-010 ,ALCAINS	1	1
s33	MATIBOM - Matadouro e Industrias de Car	Cavaleiro-Valbom-Pinhel ,6400-661 ,Valbom	0	1
s34	QUINTA DA RAZEIRA - SOCIEDADE AGRI	Parque Industrial, Lote 56 ,6300-625 ,Guarda	0	1
s35	António Cerveira Flores	Rua da Fonte nrº1 Sernedelo ,3050-382 ,Mealhada	1	0
s36	CASA DE SARMENTO, S,A,	Nossa Senhora do Ó ,3780-621 ,Peneireiro-Aguim	1	0
s37	CASA DE SARMENTO, S,A,	Rua do Canavai ,3780-179 ,São Lourenço do Bairro	1	1
s38	Virgilio dos Leitões-Restaurante Lda,	Peneireiro-EN 1 ,3780-623 ,Aguim	1	0
s39	Rei dos Leitões-Restaurantes Lda,	Av, da Restauração,17-Sernadelo ,3050-382 ,Mealhada	1	0
s40	Restaurante Fonte do Corvo, Lda,	Rua Nossa Senhora das Dores, 4-6 ,2420-403 ,Boavista	1	0
s41	Hélio dos Santos & Filhos, Lda	Rua de S, Silvestre, 371 Figueiras - Milagres ,2415-017 ,Leiria	1	0
s42	Restaurante Vidal Ferreira, Lda,	Almas de Areosa-Aguada de Cima ,3750-000 ,Águeda	1	0
s43	Evasão Animal-Comércio de Leitões, Lda,	Ponte de Viadores ,3050-184 ,Casal Comba	1	0
s44	João Dias de Carvalho	Piedade-Espinhel ,3750-406 ,Águeda	1	0
s45	Matadouros da Beira Litoral, S, A,	Zona Industrial de Taboeira ,3800-055 ,Aveiro	1	1
s46	ARMÉNIO DA CONCEIÇÃO LOURENÇO GA	Fontanhão ,3050-347 ,Mealhada	1	0
s47	Churrarocha, Lda,	Travessa da Churrascaria ,3050-352 ,Mealhada	1	0
s48	ANTÓNIO FERREIRA DOS SANTOS SOAR	Rua Outeirinhas ,3050-511 ,Vacariça	1	0
s49	Carlos Castela & Filhos, Lda,	Av, Cidade de Coimbra, nº103, Mealhada ,3050-374 ,Mealhada	1	0
s50	HA - HUGO MIGUEL ALVES ABREU, UNIP	ZONA INDUSTRIAL DE VILA VERDE, RUA H, LOTE 16 ,3770-308 ,VI	1	0

	Lisbon and Tagus Valley
	Central region of Mainland Portugal

Pure slaughterhouse
Slaughterhouse with and integrated CPC

Annex 2 – Distances (Km)

	s0	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15	s16	s17	s18	s19	s20	s21	s22	s23	s24	s25	s26	s27	s28	s29	s30	s31	s32	s33	s34	s35	s36	s37	s38	s39	s40	s41	s42	s43	s44	s45	s46	s47	s48	s49	s50
s0	0	18,5	18,6	17,9	69,1	40,8	21,5	93,9	70,4	8,3	137	24,8	39,1	33,3	129	7,9	82,2	27,1	17,6	17,9	69,6	188	141	215	216	238	217	218	186	188	131	211	225	337	306	215	218	226	217	215	137	141	230	216	243	244	216	215	218	213	244
s1	18,5	0	0,18	0,4	88,6	48,3	19,3	116	75,3	13,8	156	17,1	59,7	45,9	142	12,5	81,1	25,6	0,7	0,75	87,2	195	143	222	223	237	224	219	206	195	129	230	244	356	325	222	225	230	224	222	138	142	236	222	244	242	223	222	224	220	237
s2	18,6	0,18	0	0,5	88,7	49,2	19,4	115	75,4	13,9	155,5	17,2	59,8	46	141,5	23,2	81,2	25,7	0,8	0,95	87,8	195,1	142	223	222	238	225	220	207	196	128	225	243	357	323	220	224	233	225	221	139	140	237	224	245	240	222	221	222	219	235
s3	17,9	0,4	0,5	0	88,2	48,7	18,9	116	74,9	13,4	155	16,8	59,3	45,5	141	22,7	80,7	25,2	0,3	0,45	87,3	194	141	222	223	236	224	218	205	194	129	226	244	355	325	222	225	228	223	222	138	142	236	222	244	241	221	220,5	224	220	237
s4	69,1	88,6	88,7	88,2	0	95,8	85,4	25,6	35,7	71,6	73,5	87,6	58,6	92,6	59,5	61,2	69,5	89,9	87,9	88,1	11,6	125	78,4	152	151,5	181	154	149	123	124	77,9	148	162	273	243	153	155	158	154	152	74,1	77,6	166	152	180	184	185	152	154	150	181
s5	40,8	48,3	49,2	48,7	95,8	0	53,8	119	96,9	36,9	163	56	30,6	8,9	149	38,2	130	58,3	49,3	49,5	96,3	214	167	241	242	270	243	238	212	214	162	237	251	363	332	241	244	247	243	241	163	167	256	241	269	273	241	240	244	239	240
s6	21,5	19,3	19,4	18,9	85,4	53,8	0	98,1	58,4	18,9	152	11	56,5	49,8	138	26,1	80	4,6	18,6	18,8	84,4	178	126	205	204	220	207	202	200	178	112	208	241	352	322	206	208	211	207	205	122	125	220	205	227	225	205	204	207	203	223
s7	93,9	116	115	116	25,6	119	98,1	0	28,8	94,4	64,7	97,1	81,3	115	50,7	83,9	42,3	95,7	114	115	36	111	54,9	138	140	163	140	135	115	111	45	139	153	265	234	139	141	154	140	138	50,5	54	152	138	166	168	138	140	140	136	166
s8	70,4	75,3	75,4	74,9	35,7	96,9	58,4	28,8	0	72,3	99,6	58,4	59,2	93,3	85,7	61,9	25,2	57	74,9	75,1	40,4	145	93,6	173	175	187	175	169	149	145	80	174	188	300	269	173	176	181	180	173	89,2	92,7	187	173	195	193	173	172	175	171	190
s9	8,3	13,8	13,9	13,4	71,6	36,9	18,9	94,4	72,3	0	139	22	42,9	33,3	125	10,5	79,9	24,5	12,6	12,8	71	190	142	217	218	236	219	214	189	190	128	213	227	339	308	218	220	223	219	217	137	141	232	218	246	240	218	217	220	216	245
s10	137	156	156	155	73,5	163	152	64,7	99,6	139	0	154	125	159	35,6	128	132	157	155	156	84,8	116	88,9	145	144	174	147	141	62,1	116	88,4	124	88,8	200	170	145	148	160	147	145	84,5	88,1	159	145	173	177	145	144	147	143	173
s11	24,8	17,1	17,2	16,8	87,6	56	11	97,1	58,4	22	154	0	59,3	52,7	141	28,9	79,8	9,3	16,4	16,6	87,2	178	126	205	204	220	207	206	205	177	112	208	244	355	325	206	208	214	207	205	121	125	219	205	227	224	205	204	207	203	222
s12	39,1	59,7	59,8	59,3	58,6	30,6	56,5	81,3	59,2	42,9	125	59,3	0	29,5	110	27,5	85,1	57,4	55,5	55,7	55,9	175	129	202	203	232	204	199	174	175	128	199	212	324	293	203	205	208	204	202	124	128	217	203	231	235	203	202	205	201	231
s13	33,3	45,9	46	45,5	92,6	8,9	49,8	115	93,3	33,3	159	52,7	29,5	0	145	35	126	55	46	46,2	91,3	210	164	238	240	267	240	235	209	210	159	234	248	359	329	239	241	244	240	238	160	163	252	238	266	270	238	237	240	236	266
s14	129	142	142	141	59,5	149	138	50,7	85,7	125	35,6	141	110	145	0	113	98,3	142	140	141	69,9	83,7	73,9	113	114	142	115	109	67,3	83,5	73,4	92,2	124	235	205	113	116	119	115	113	69,6	73,1	127	113	141	145	113	112	115	111	141
s15	7,9	12,5	23,2	22,7	61,2	38,2	26,1	83,9	61,9	10,5	128	28,9	27,5	35	113	0	85,8	30,4	22,4	22,6	59,3	179	132	206	208	235	208	203	177	178	132	202	216	327	297	206	209	212	208	206	128	131	220	206	234	238	206	205	208	204	234
s16	82,2	81,1	81,2	80,7	69,5	130	80	42,3	25,2	79,9	132	79,8	85,1	126	98,3	85,8	0	77,6	95,5	95,7	80,9	112	60,5	140	138	154	142	136	135	112	46,9	143	221	293	302	140	143	148	142	140	56,1	59,6	154	140	162	159	140	139	140	138	157
s17	27,1	25,6	25,7	25,2	89,9	58,3	4,6	95,7	57	24,5	157	9,3	57,4	55	142	30,4	77,6	0	20,5	20,7	68,8	175	123	203	204	203	205	199	187	175	110	206	225	337	306	203	206	211	205	203	119	123	217	203	225	222	203	202	205	201	220
s18	17,6	0,7	0,8	0,3	87,9	49,3	18,6	114	74,9	12,6	155	16,4	55,5	46	140	22,4	95,5	20,5	0	0,22	87,1	194	142	221	222	236	224	218	205	194	129	230	243	355	324	222	224	229	224	220	138	141	236	222	244	241	222	221	224	220	239
s19	17,9	0,75	0,95	0,45	88,1	49,5	18,8	115	75,1	12,8	156	16,6	55,7	46,2	141	22,6	95,7	20,7	0,22	0	87,2	194,1	143	222	223	237	225	219	206	193	128	229	242	354	323	221	223	228	224	222	140	143	238	224	242	239	220	219	222	220,5	237
s20	69,6	87,2	87,8	87,3	11,6	96,3	84,4	36	40,4	71	84,8	87,2	55,9	91,3	69,9	59,3	80,9	68,8	87,1	87,2	0	135	89,2	163	161	192	165	160	134	135	88,7	159	173	284	254	164	166	169	165	163	84,9	88,4	177	163	191	195	163	162	165	161	191
s21	188	195	195	194	125	214	178	111	145	190	116	178	175	210	83,7	179	112	175	194	194	135	0	69,1	39,1	39,4	68,5	41,3	35,9	58,2	0,15	68,6	40,5	146	193	181	39,5	42,3	45,2	41,2	39,2	64,8	48,1	53,6	39,6	67,5	71,3	39,7	38,7	41,6	37,4	67,3
s22	141	143	142	141	78,4	167	126	54,9	93,6	142	88,9	126	129	164	73,9	132	60,5	123	142	143	89,2	69,1	0	96,5	96,7	110	98,6	93,2	74,1	69	10,2	99,5	177	250	258	96,8	99,6	102	98,6	95,6	5,7	5,9	111	96,9	125	115	97	96,1	98,9	94,9	113
s23	215	222	223	222	152	241	205	138	173	217	145	205	202	238	113	206	140	203	221	222	163	39,1	96,5	0	0,29	40,8	2,2	8,3	89,4	40,3	96,6	46,6	178	160	147	0,35	3,2	11,7	2,1	0,11	92,7	96,2	14,5	6	22,1	43,7	1,6	1,4	5,4	3,8	17,7
s24	216	223	222	223	152	242	204	140	175	218	144	204	203	240	114	208	138	204	222	223	161	39,4	96,7	0,29	0	40,6	1,9	10	89,1	40	96,3	46,3	177	161	148	0,4	2,9	11,4	1,8	0,45	92,4	96	14,2	5,7	21,8	43,4	1,4	2,4	6,3	3,6	17,4
s25	238	237	238	236	181	270	220	163	187	236	174	220	232	267	142	235	154	203	236	237	192	68,5	110	40,8	40,6	0	31,8	44	116	67,2	115	80,8	205	172	160	39,6	31,4	28,3	32,2	39,3	120	113	25	39,6	18,6	9,7	39,8	38,8	41,7	37,5	18,3
s26	217	224	225	224	154	243	207	140	175	219	147	207	204	240	115	208	142	205	224	225	165	41,3	98,6	2,2	1,9	31,8	0	11,6	90,7	41,6	97,9	47,9	179	162	150	2,1	1,1	9,6	0,4	2,1	94	97,5	12,4	7,3	20	35,6	2,9	3,9	7,9	5,2	15,6
s27	218	219	220	218	149	238	202	135	169	214	141	206	199	235	109	203	136	199	218	219	160	35,9	93,2	8,3	10	44	11,6	0	85,4	32,3	92,6	33,9	174	170	158	9,5	12,3	20,8	11,2	9,2	88,8	92,3	23,6	4,6	31,2	47,5	9,7	6,9	5	6,2	26,2
s28	186	206	207	205	123	212	200	115	149	189	62,1	205	174	209	67,3	177	135	187	205	206	134	58,2	74,1	89,4	89,1	116	90,7	85,4	0	57,5	78,1	66,1	91,6	203	172	86,9	89,7	102	88,7	86,7	72,3	69,2	101	87	115	119	87,2	86,2	89,1	84,9	115
s29	188	195	196	194	124	214	178	111	145	190	116	177	175	210	83,5	178	112	175	194	193	135	0,15	69	40,3	40	67,2	41,6	32,3	57,5	0	68,5	40,3	146	193	181	39,3	42,1	45	41,1	39,1	64,6	47,9	53,5	32,7	67,4	71,2	39,6	38,6	41,4	37,3	67,2
s30	131	129	128	129	77,9	162	112	45	80	128	88,4	112	128	159	73,4	132	46,9	110	129	128	88,7	68,6	10,2	96,6	96,3	115	97,9	92,6	78,1	68,5	0	99,3	177	250	157	96,9	99,3	102	98,3	96,3	6,3	10	111	96,6	125	126	96,8	95,8	101	94,5	124
s31	211	230	225	226	148	237	208	139	174	213	124	208	199	234	92,2	202	143	206	230	229	159	40,5	99,5	46,6	46,3	80,8	47,9	33,9	66,1	40,3	99,3	0	156	160	148	45,5	48,3	58,5	47,3	45,2	101	104	59,7	41,5	80,2	84	45,8	44,8	35,6	42,2	62,9
s32	225	244	243	244	162	251	241	153	188	227	88,8	244	212	248	124	216	221	225	243	242	173	146	177	178	177	205	179	174	91,6	146	177	156	0	113	82,2	176	179	191	177	175	173	177	190	176	204	208	176	175	178	174	204
s33	337	356	357	355	273	363	352	265	300	339	200	355	324	359	235	327	293	337	355	354	284	193	250	160	161	172	162	170	203	193	250	160	113	0	35	160	163	171	162	160	234	237	170	163	158	164	161	158	157	161	178
s34	306	325	323	325	243	332	322	234	269	308	170	325	293	329	205	297	302	306	324	323	254	181	258	147	148	160	150	158	172	181	157	148	82,2	35	0	148	151	158	150	148	253	257	158	153	146	151	148	146	145	149	166
s35	215	222	220	222	153	241	206	139	173	218	145	206	203	239	113	206	140	203	222	221	164	39,5	96,8	0,35	0,4	39,6	2,1	9,5	86,9	39,3	96,9	45,5	176	160	148	0	3	15,5	2	0,45	92,6	96,1	14,4	5,8	21,9	43,5	1,5	1,6	5,5	3,7	17,6
s36	218	225	224	225	155	244	208	141	176	220	148	208	205	241	116	209	143	206	224	223	166	42,3	99,6	3,2	2,9	31,4	1,1	12,3	89,7	42,1	99,3	48,3	179	163	151	3	0	12,9	1,5	3,1	95,1	98,6	11,8	8,3	19,3	34,9	4	5	8,9	6,2	15
s37	226	230	233	228	158	247	211	154	181	223	160	214	208	244	119	212	148	211	229	228	169	45,2	102	11,7	11,4	28,3	9,6	20,8	102	45	102	58,5	191	171	158	15,5	12,9	0	13,9	15,5	108	111	1,2	20,8	9,1	37,4	16,4	17,4	21,4	18,6	9,3
s38	217	224	225	223	154	243	207	140	180	219	147	207	204	240	115	208	142	205	224	224	165	41,2	98,6	2,1	1,8	32,2	0,4	11,2	88,7	41,1	98,3	47,3	177	162	150	2	1,5	13,9	0	2	94	97,5	12,8	7,2	20,3	36	2,9	3,9	7,9	5,1	16
s39	215	222	221	222	152	241	205	138	173	217	145	205	202	238	113	206	140	203	220	222	163	39,2	95,6	0,11	0,45	39,3	2,1	9,2	86,7	39,1	96,3	45,2	175	160	148	0,45	3,1	15,5	2	0	92	95,5	14,4	5,2	22	42,9	0,9	1,9	5,8	3,1	17,6
s40	137	138	139	138	74,1	163	122	50,5	89,2	137	84,5	121	124	160	69,6	128	56,1	119	138	140	84,9	64,8	5,7	92,7	92,4	120	94	88,8	72,3	64,6	6,3	101	173	234	253	92,6	95,1	108	94	92	0	5	110	96	126	127	96,1	95,1	98	93,8	124
s41	141	142	140	142	77,6	167	125	54	92,7	141	88,1	125	128	163	73,1	131	59,6	123	141	143	88,4	48,1	5,9	96,2	96	113	97,5	92,3	69,2	47,9	10	104	177	237	257	96,1	98,6	111	97,5	95,5	5	0	111	96,2	124	119	96,4	95,4	98,3	94,1	124,5
s42	230	236	237	236	166	256	220	152	187	232	159	219	217	252	127	220	154	217	236	238	177	53,6	111	14,5	14,2	25	12,4	23,6	101	53,5	111	59,7	190	170	158	14,4	11,8	1,2	12,8	14,4	110	111	0	19,7	10,5	36,8	15,3	16,3	20,3	17,5	8,7
s43	216	222	224	222	152	241	205	138	173	218	145	205	203	238	113	206	140	203	222	224	163	39,6	96,9	6	5,7	39,6	7,3	4,6	87	32,7	96,6	41,5	176	163	153	5,8	8,3	20,8	7,2	5,2	96	96,2	19,7	0	26,8	43,1	5,3	4,4	4,5	1,8	22,4
s44	243	244	245	244	180	269	227	166	195	246	173	227	231	266	141	234	162	225	244	242	191	67,5	125	22,1	21,8	18,6	20	31,2	115	67,4	125	80,2	204	158	146	21,9	19,3	9,1	20,3	22	126	124	10,5	26,8	0	22,3	23,2	24,2	28,1	25,4	6,8
s45	244	242	240	241	184	273	225	168	193	240	177	224	235	270	145	238	159	222	241	239	195	71,3	115	43,7	43,4	9,7	35,6	47,5	119	71,2	126	84	208	164	151	43,5	34,9	37,4	36	42,9	127	119	36,8	43,1	22,3	0	43,4	42,4	45,3	41,1	21,9
s46	216	223	222	221	185	241	205	138	173	218	145	205	203	238	113	206	140	203	222	220	163	39,7	97	1,6	1,4	39,8	2,9	9,7	87,2	39,6	96,8	45,8	176	161	148	1,5	4	16,4	2,9	0,9	96,1	96,4	15,3	5,3	23,2	43,4	0	1,1	5,1	2,3	19,2
s47	215	222	221	221	152	240	204	140	172	217	144	204	202	237	112	205	139	202	221	219	162	38,7	96,1	1,4	2,4	38,8	3,9	6,9	86,2	38,6	95,8	44,8	175	158	146	1,6	5	17,4	3,9	1,9	95,1	95,4	16,3	4,4	24,2	42,4	1,1	0	4,6	2,8	19,6
s48	218	224	222	224	154	244	207	140	175	220	147	207	205	240	115	208	140	205	224	222	165	41,6	98,9	5,4	6,3	41,7	7,9	5	89,1	41,4	101	35,6	178	157	145	5,5	8,9	21,4	7,9	5,8	98	98,3	20,3	4,5	28,1	45,3	5,1	4,6	0	4,6	23,6
s49	213	220	219	220	150	239	203	136	171	216	143	203	201	236	111	204	138	201	220	221	161	37,4	94,9	3,8	3,6	37,5	5,2	6,2	84,9	37,3	94,5	42,2	174	161	149	3,7	6,2	18,6	5,1	3,1	93,8	94,1	17,5	1,8	25,4	41,1	2,3	2,8	4,6	0	20,7
s50	244	237	235	237	181	240	223	166	190	245	173	222	231	266	141	234	157	220	239	237	191	67,3	113	17,7	17,4	18,3	15,6	26,2	115	67,2	124	62,9	204	178	166	17,6	15	9,3	16	17,6	124	124,5	8,7	22,4	6,8	21,9	19,2	19,6	23,6	20,7	0

Annex 3 – Tolls (€)

	s0	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15	s16	s17	s18	s19	s20	s21	s22	s23	s24	s25	s26	s27	s28	s29	s30	s31	s32	s33	s34	s35	s36	s37	s38	s39	s40	s41	s42	s43	s44	s45	s46	s47	s48	s49	s50
s0	0	0	0	0	5,05	9,5	0,7	5,05	3,5	0	10,8	1,1	1,8	9,5	9,7	0	5,9	1,55	0	0	4,4	14	3,5	17	16,8	19,2	16,8	17,4	14	15,1	9,1	15	16,4	22,2	22,2	16,75	16,75	16,75	16,75	16,75	10,5	10,5	17	16	20,2	19,8	16,75	16,8	16,8	16,8	16,8
s1	0	0	0	0	6,3	9,5	0	6,15	3,6	0	13,6	0	4,6	9,5	6,3	0	5,4	1,6	0	0	7,2	13	9,4	20	19,6	18,7	15,8	16,9	16,8	14,1	8,6	17,8	19,2	25	25	15,8	15,8	15,8	15,8	15,8	9	9,4	16	15,1	20,65	19,3	15,8	15,8	15,8	15,8	15,8
s2	0	0	0	0	6,3	9,5	0	6,15	3,6	0	13,6	0	4,6	9,5	6,3	0	5,4	1,6	0	0	7,2	13	9,4	20	19,6	18,7	15,8	16,9	16,8	14,1	8,6	17,8	19,2	25	25	15,8	15,8	15,8	15,8	15,8	9	9,4	16	15,1	20,65	19,3	15,8	15,8	15,8	15,8	15,8
s3	0	0	0	0	6,3	9,5	0	6,15	3,6	0	13,6	0	4,6	9,5	6,3	0	5,4	1,6	0	0	7,2	13	9,4	20	19,6	18,7	15,8	16,9	16,8	14,1	8,6	17,8	19,2	25	25	15,8	15,8	15,8	15,8	15,8	9	9,4	16	15,1	20,65	19,3	15,8	15,8	15,8	15,8	15,8
s4	5,05	6,3	6,3	6,3	0	18	7,2	2,25	2,3	10,1	0,85	11	7	18,1	4,3	3,25	4	2,55	5,75	5,75	0	8,9	5,5	12	11,7	13,6	11,7	11,4	8,9	8,9	5,45	9,95	11,35	17,15	17,15	11,7	11,7	11,7	11,7	11,7	5,45	5,45	12	11	15,15	14,15	11,7	11,7	11,7	11,7	11,7
s5	9,5	9,5	9,5	9,5	18,1	0	13	16,3	15	12,4	22,1	12	0	0	21	13,1	20	13,9	12,4	12,35	0	25,2	22	28	28	29,9	28	27,7	25,2	26,3	21,8	26,25	29,35	33,45	33,45	28	28	28	28	28	21,8	21,8	28	27,3	28	30,45	29,85	29,9	29,9	29,9	29,9
s6	0,65	0	0	0	7,2	13	0	5,1	2,6	0,65	9,45	0	0,7	10,2	7,1	0	3,3	0	0	0	0	12	7,1	15	14,8	17,7	14,8	15,8	12,6	13,1	7,95	13,05	13,05	20,85	20,85	14,75	14,75	14,75	14,75	14,75	7,95	7,95	15	14,8	14,75	17,65	14,75	14,8	14,8	14,8	14,8
s7	5,05	6,15	6,2	6,15	2,25	16	5,1	0	0	5,4	3,35	4,2	3,3	13,5	1	3,95	0	5,1	5,75	5,75	0	6,5	1,3	9,3	9,3	10,6	9,3	8,7	6,5	7,6	1,25	7,55	8,95	14,75	14,75	9,3	9,3	9,3	9,3	9,3	1,25	1,25	9,3	8,55	8,55	11,15	9,3	9,3	9,3	9,3	9,3
s8	3,5	3,6	3,6	3,6	2,25	15	2,6	0	0	3,45	7,4	1,7	1,7	11,9	5	6,3	0	0	3,6	3,6	1,9	5,25	1,3	8,1	8,05	14,4	8,05	12,5	10,6	6,35	1,25	6,35	13	18,8	18,8	8,05	8,05	8,05	8,05	8,05	1,25	1,25	8,1	8,05	8,05	14,35	8,05	8,05	8,05	8,05	8,05
s9	0	0	0	0	10,1	12	0,7	5,4	3,5	0	11,2	0,5	2,2	9,5	8,8	0	5,3	0,9	0	0	3,9	14,3	9,3	17	17,1	18,6	17,1	16,7	14,3	15,4	8,85	15,35	16,75	22,55	22,55	17,1	17,1	17,1	17,1	17,1	8,85	8,85	17	17,1	17,1	18,55	17,1	17,1	17,1	17,1	17,1
s10	10,8	13,6	14	13,6	0,85	22	9,5	3,35	7,4	11,2	0	12	9	18,5	0,9	9,7	11	8,3	11,5	11,5	5,8	6,15	6,4	11	10,5	12,4	10,5	10,2	0	6,15	6,4	6,15	5,6	11,4	11,4	10,5	10,5	10,5	10,5	10,5	6,4	6,4	11	10,5	10,5	12,35	10,5	10,5	10,5	10,5	10,5
s11	1,1	0	0	0	11,2	12	0	4,2	1,7	0,45	12,3	0	0,7	10,2	7,1	0	3,3	0	0	0	0	12	7,1	15	14,8	17,7	14,8	15,8	12,6	13,1	7,95	13,05	13,05	20,85	20,85	14,75	14,75	14,75	14,75	14,75	7,95	7,95	15	14,8	14,75	17,65	14,75	14,8	14,8	14,8	14,8
s12	1,8	4,6	4,6	4,6	7	0	0,7	3,25	1,7	2,15	9	0,7	0	0	6,6	2,85	4,6	0	4,05	4,05	0	12,2	8,7	15	15	16,8	15	14,6	12,2	13,3	8,7	13,2	14,6	20,4	20,4	14,95	14,95	14,95	14,95	14,95	8,7	8,7	15	15	14,95	16,8	16,8	16,8	16,8	16,8	16,8
s13	9,5	9,5	9,5	9,5	18,1	0	10	13,5	12	9,5	18,5	10	0	0	21	13,1	20	13,9	12,4	12,35	0	25,2	22	28	28	29,9	28	27,7	25,2	26,3	21,8	26,25	29,35	33,45	33,45	28	28	28	28	28	21,8	21,8	28	27,3	28	30,45	29,85	29,9	29,9	29,9	29,9
s14	9,7	6,3	6,3	6,3	4,25	21	7,1	0,95	5	8,75	0,85	7,1	6,6	21	0	8,6	4,2	7,2	10,4	10,4	4,7	5,3	1,3	9,7	9,65	11,5	9,65	9,3	4,25	5,3	1,25	6	6,45	12,25	12,25	9,65	9,65	9,65	9,65	9,65	1,25	1,25	9,7	9,65	9,65	11,5	9,65	9,65	9,65	9,65	9,65
s15	0	0	0	0	3,25	13	0	3,95	6,3	0	9,7	0	2,9	13,1	8,6	0	5,3	0,9	0	0	3,9	14,3	9,3	17	17,1	18,6	17,1	16,7	14,3	15,4	8,85	15,35	16,75	22,55	22,55	17,1	17,1	17,1	17,1	17,1	8,85	8,85	17	17,1	17,1	18,55	17,1	17,1	17,1	17,1	17,1
s16	5,9	5,4	5,4	5,4	3,95	20	3,3	0	0	5,25	10,6	3,3	4,6	20,1	4,2	5,25	0	2,9	5,4	5,4	5	7,6	3,6	10	10,4	13,3	10,4	11,5	6,3	8,7	4	8,7	16,15	12,6	12,6	10,4	10,4	10,4	10,4	10,4	3,6	3,6	10	10,4	10,4	13,3	10,4	10,4	10,4	10,4	10,4
s17	1,55	1,6	1,6	1,6	2,55	14	0	5,1	0	0,9	8,3	0	0	13,9	7,2	0,9	2,9	0	0	0	0	12	7,1	15	14,8	17,7	14,8	15,8	12,6	13,1	7,95	13,05	13,05	20,85	20,85	14,75	14,75	14,75	14,75	14,75	7,95	7,95	15	14,8	14,75	17,65	14,75	14,8	14,8	14,8	14,8
s18	0	0	0	0	5,75	12	0	5,75	3,6	0	11,5	0	4,1	12,4	10	0	5,4	0	0	0	7,2	13	9,4	20	19,6	18,7	15,8	16,9	16,8	14,1	8,6	17,8	19,2	25	25	15,8	15,8	15,8	15,8	15,8	9	9,4	16	15,1	20,65	19,3	15,8	15,8	15,8	15,8	15,8
s19	0	0	0	0	5,75	12	0	5,75	3,6	0	11,5	0	4,1	12,4	10	0	5,4	0	0	0	7,2	13	9,4	20	19,6	18,7	15,8	16,9	16,8	14,1	8,6	17,8	19,2	25	25	15,8	15,8	15,8	15,8	15,8	9	9,4	16	15,1	20,65	19,3	15,8	15,8	15,8	15,8	15,8
s20	4,4	7,2	7,2	7,2	0	0	0	0	1,9	3,85	5,75	0	0	0	4,7	3,85	5	0	7,2	7,2	0	8,9	5,5	12	11,7	13,6	11,7	11,4	8,9	10	5,45	9,95	11,35	17,15	17,15	11,7	11,7	11,7	11,7	11,7	5,45	5,45	12	11,7	11,7	14,15	11,7	11,7	11,7	11,7	11,7
s21	14	13	13	13	8,9	25	12	6,5	5,3	14,3	6,15	12	12	25,2	5,3	14,3	7,6	12	13	13	8,9	0	3,5	1,7	1,7	3,55	1,7	1,35	1,05	0	3,45	0	3,7	3,9	3,9	1,7	1,7	1,7	1,7	1,7	1,2	1,2	1,7	1,7	1,7	3,55	1,7	1,7	1,7	1,7	1,7
s22	3,5	9,4	9,4	9,4	5,45	22	7,1	1,25	1,3	9,25	6,4	7,1	8,7	21,8	1,3	9,25	3,6	7,05	9,4	9,4	5,5	3,45	0	6,3	6,25	9,3	6,25	7,45	0	4,55	0	4,55	12	8,45	8,45	6,25	6,25	6,25	6,25	6,25	0	0	6,3	6,25	6,25	9,3	6,25	6,25	6,25	6,25	6,25
s23	16,8	19,6	20	19,6	11,7	28	15	9,3	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	19,6	19,55	12	1,7	6,3	0	0	1,85	0	0	5,4	1,7	6,25	4,57	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s24	16,8	19,6	20	19,6	11,7	28	15	9,3	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	19,6	19,55	12	1,7	6,3	0	0	1,85	0	0	5,4	1,7	6,25	4,57	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s25	19,2	18,7	19	18,7	13,6	30	18	10,6	14	18,6	12,4	18	17	29,9	12	18,6	13	17,7	18,7	18,7	14	3,55	9,3	1,9	1,85	0	0	1,85	7,2	3,55	9,3	2,6	2,6	9,05	10,25	1,85	1,85	1,85	1,85	1,85	8,35	8,35	1,9	1,85	0	0	1,85	1,85	1,85	1,85	1,85
s26	16,8	15,8	16	15,8	11,7	28	15	9,3	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	0	0	0	5,4	1,7	6,25	4,57	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s27	17,4	16,9	17	16,9	11,4	28	16	8,7	13	16,7	10,2	16	15	27,7	9,3	16,7	11	15,8	16,9	16,85	11	1,35	7,5	0	0	1,85	0	0	5,4	1,7	6,25	4,57	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s28	14	16,8	17	16,8	8,9	25	13	6,5	11	14,3	0	13	12	25,2	4,3	14,3	6,3	12,6	16,8	16,75	8,9	1,05	0	5,4	5,4	7,2	5,4	5,4	0	1,05	2,15	1,05	2,65	8,45	8,45	5,45	5,45	5,45	5,45	5,45	0	0	5,4	5,4	5,4	7,25	5,4	5,4	5,4	5,4	5,4
s29	15,1	14,1	14	14,1	8,9	26	13	7,6	6,4	15,4	6,15	13	13	26,3	5,3	15,4	8,7	13,1	14,1	14,1	10	0	4,6	1,7	1,7	3,55	1,7	1,7	1,05	0	3,45	0	3,7	3,9	3,9	1,7	1,7	1,7	1,7	1,7	1,2	1,2	1,7	1,7	1,7	3,55	1,7	1,7	1,7	1,7	1,7
s30	9,1	8,6	8,6	8,6	5,45	22	8	1,25	1,3	8,85	6,4	8	8,7	21,8	1,3	8,85	4	7,95	8,6	8,6	5,5	3,45	0	6,3	6,25	9,3	6,25	6,25	2,15	3,45	0	4,55	12	8,45	8,45	6,25	6,25	6,25	6,25	6,25	0	0	6,3	6,25	6,25	9,3	6,25	6,25	6,25	6,25	6,25
s31	15	17,8	18	17,8	9,95	26	13	7,55	6,4	15,4	6,15	13	13	26,3	6	15,4	8,7	13,1	17,8	17,8	10	0	4,6	4,6	4,57	2,6	4,57	4,57	1,05	0	4,55	0	3,7	2,95	2,95	0	0	0	0	0	4,55	4,55	0	0	0	2,6	0	0	0	0	0
s32	16,4	19,2	19	19,2	11,4	29	13	8,95	13	16,8	5,6	13	15	29,4	6,5	16,8	16	13,1	19,2	19,2	11	3,7	12	8,1	8,05	2,6	8,05	8,05	2,65	3,7	12	3,7	0	5,8	5,8	8,05	8,05	8,05	8,05	8,05	12	12	8,1	8,05	8,05	9,9	8,05	8,05	8,05	8,05	8,05
s33	22,2	25	25	25	17,2	33	21	14,8	19	22,6	11,4	21	20	33,5	12	22,6	13	20,9	25	25	17	3,9	8,5	3	2,95	9,05	2,95	2,95	8,45	3,9	8,45	2,95	5,8	0	0	2,95	2,95	2,95	2,95	2,95	8,45	8,45	3	2,95	2,95	9,55	2,95	2,95	2,95	2,95	2,95
s34	22,2	25	25	25	17,2	33	21	14,8	19	22,6	11,4	21	20	33,5	12	22,6	13	20,9	25	25	17	3,9	8,5	4,2	4,15	10,3	4,15	4,15	8,45	3,9	8,45	2,95	5,8	0	0	4,15	4,15	4,15	4,15	4,15	9,65	9,65	4,2	4,15	4,15	11,45	4,15	4,15	4,15	4,15	4,15
s35	16,8	15,8	16	15,8	11,7	28	15	9,3	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,45	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s36	16,8	15,8	16	15,8	11,7	28	15	9,3	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,45	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s37	16,8	15,8	16	15,8	11,7	28	15	9,3	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,45	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s38	16,8	15,8	16	15,8	11,7	28	15	9,3	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,45	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s39	16,8	15,8	16	15,8	11,7	28	15	9,3	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,45	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s40	10,5	9	9	9	5,45	22	8	1,25	1,3	8,85	6,4	8	8,7	21,8	1,3	8,85	3,6	7,95	9	9	5,5	1,2	0	6,3	6,25	8,35	6,25	6,25	0	1,2	0	4,55	12	8,45	9,65	6,25	6,25	6,25	6,25	6,25	0	0	6,3	6,25	6,25	9,3	6,25	6,25	6,25	6,25	6,25
s41	10,5	9,4	9,4	9,4	5,45	22	8	1,25	1,3	8,85	6,4	8	8,7	21,8	1,3	8,85	3,6	7,95	9,4	9,4	5,5	1,2	0	6,3	6,25	8,35	6,25	6,25	0	1,2	0	4,55	12	8,45	9,65	6,25	6,25	6,25	6,25	6,25	0	0	6,3	6,25	6,25	9,3	6,25	6,25	6,25	6,25	6,25
s42	16,8	15,8	16	15,8	11,7	28	15	9,3	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,4	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	0	0	0	0	0	0
s43	16	15,1	15	15,1	11	27	15	8,55	8,1	17,1	10,5	15	15	27,3	9,7	17,1	10	14,8	15,1	15,05	12	1,7	6,3	0	0	1,85	0	0	5,4	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s44	20,2	20,7	21	20,7	15,2	28	15	8,55	8,1	17,1	10,5	15	15	28	9,7	17,1	10	14,8	20,7	20,65	12	1,7	6,3	0	0	0	0	0	5,4	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	0	0	0	0	0	0
s45	19,8	19,3	19	19,3	14,2	30	18	11,2	14	18,6	12,4	18	17	30,5	12	18,6	13	17,7	19,3	19,3	14	3,55	9,3	1,9	1,85	0	1,85	1,85	7,25	3,55	9,3	2,6	9,9	9,55	11,45	1,85	1,85	1,85	1,85	1,85	9,3	9,3	0	1,85	0	0	1,85	1,85	1,85	1,85	1,85
s46	16,8	15,8	16	15,8	11,7	30	15	9,3	8,1	17,1	10,5	15	17	29,9	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,4	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s47	16,8	15,8	16	15,8	11,7	30	15	9,3	8,1	17,1	10,5	15	17	29,9	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,4	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s48	16,8	15,8	16	15,8	11,7	30	15	9,3	8,1	17,1	10,5	15	17	29,9	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,4	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s49	16,8	15,8	16	15,8	11,7	30	15	9,3	8,1	17,1	10,5	15	17	29,9	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,4	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0
s50	16,8	15,8	16	15,8	11,7	30	15	9,3	8,1	17,1	10,5	15	17	29,9	9,7	17,1	10	14,8	15,8	15,8	12	1,7	6,3	0	0	1,85	0	0	5,4	1,7	6,25	0	8,05	2,95	4,15	0	0	0	0	0	6,25	6,25	0	0	0	1,85	0	0	0	0	0

Annex 4 – Quantities generated by each slaughterhouse (Kgs)

	Capacity
s0	0
s1	885,918
s2	885,918
s3	2219,300
s4	6851,924
s5	4632,624
s6	4632,624
s7	6851,924
s8	4632,624
s9	4632,624
s10	4632,624
s11	4632,624
s12	4632,624
s13	6851,924
s14	4632,624
s15	4632,624
s16	4632,624
s17	4632,624
s18	885,918
s19	885,918
s20	4632,624
s21	1801,687
s22	49,441
s23	49,441
s24	49,441
s25	49,441
s26	49,441
s27	49,441
s28	1801,687
s29	1677,832
s30	1677,832
s31	1801,687
s32	1801,687
s33	1677,832
s34	1677,832
s35	49,441
s36	49,441
s37	1801,687
s38	49,441
s39	49,441
s40	49,441
s41	49,441
s42	49,441
s43	49,441
s44	49,441
s45	1801,687
s46	49,441
s47	49,441
s48	49,441
s49	49,441
s50	49,441

Annex 5 – Implemented code in order to transfer Excel data to GAMS for scenarios 1 and 2

```
Set i row labels
;
Alias(i,j);

Parameter dist(i,j)
          T
          c;

$onecho > tasks.txt
dset=i rng=a1 rdim=1
par=dist rng=Distances1!a1 rdim=1 cdim=1
par=T rng=Tolls!a1 rdim=1 cdim=1
par=c rng=Capacity_Final!a1 rdim=1
$offecho

$call GDXXRW Slaughterhouses.xlsx input=in trace=3 @tasks.txt
$GDXIN in.gdx
$LOAD i
$LOAD dist T c
$gdxin

Display i, j, dist, T, c;
```

Annex 6 – Implemented code in order to transfer Excel data to GAMS for scenario 3

```
Set i row labels

;


Alias(i,j);


Parameter dist(i,j)

          T(i,j)

          c(i);


$onecho > tasks.txt

dset=i rng=a1:a22 rdim=1

par=dist rng=Distances2!a1 rdim=1 cdim=1

par=T rng=Tolls2!a1 rdim=1 cdim=1

par=c rng=Capacity2!a1 rdim=1

$offecho


$call GDXXRW Slaughterhouses.xlsx trace=3 @tasks.txt

$GDXIN Slaughterhouses.gdx

$LOAD i

$LOAD dist T c

$gdxin


Display i, j, dist, T, c;
```

Annex 7 - Code implemented in GAMS for scenario 1 and 3

```
Sets

i slaughterhouses

k vehicles /k1*k6/;

Alias (i,j);

Parameters

c (i) quantity of by-products in slaughterhouse i

T (i,j) toll value (€) that must be paid in order to traverse arc ij

dist (i,j) absolute distance (km) of arc ij

time (i,j) needed time to transverse arc ij;

Scalars

Cap capacity of each vehicle (Kgs) /32000/

d transportation cost (€ per Km) /1.15/

v average speed of every truck (km per hour) /80/

H worker salary (€ per hour) /5.54/;

*--------Load all Excel inputs--------*

$ gdxin in.gdx

$ load i

$ load dist T c

$ gdxin

Variables

u (i) truck position (MTZ variable)

X (i,j,k) if vehicle k transverses ij

dur (k) final duration of each truck

load (k) load carried by each truck

z objective variable;

Integer variable

u (i);

time (i,j) = dist (i,j) / v + 0.5;

Binary Variable

X (i,j,k) if vehicle k transverses ij;

Equations

Eq1 (j,k)    The depot is always left

Eq2 (j,k)    The depot is always visited

Eq3 (j)      Each slaughterhouse is visited once

Eq4 (j)      Each slaughterhouse is left once
```

```
Eq5  (k,i)    Flow continuity respected

Eq6  (k)      Truck capacity is respected

Eq7  (i,j,k)  Subtours elimination (MTZ)

Eq8  (k)      Duration of each truck lower than 8h

objective     Objective function

Eq10( k)      Final duration

Eq13  (k)     Load equation

;

Eq1(j,k)$(ord(j) eq 1).. sum((i)$(ord(i) gt 1), X(j,i,k)) =L= 1;

Eq2(j,k)$(ord(j) eq 1).. sum((i)$(ord(i) gt 1), X(i,j,k)) =L= 1;

Eq3(j)$(ord(j) gt 1).. sum((i,k)$(ord(i) <> ord(j)), X(i,j,k)) =E= 1;

Eq4(j)$(ord(j) gt 1).. sum((i,k)$(ord(i) <> ord(j)), X(j,i,k)) =E= 1;

Eq5(k,i)..  sum(j, x(i,j,k)) =E= sum(j, X(j,i,k));

Eq6(k).. sum((i,j)$(ord(i) gt 1 and (ord(i) <> ord(j))), x(j,i,k)*c(i)) =L= Cap;

Eq7(j,i,k)$(ord(j) gt 1 and ord(i) gt 1 and ord(j) <> ord(i)).. u(j) - u(i) +
card(i)*x(j,i,k) =L= card(i)-1;

Eq8  (k)..sum((i,j)$(ord(i)<>ord(j)),time(i,j)*X(i,j,k))=l=16;

Objective.. z =e=
sum((i,j,k),dist(i,j)*X(i,j,k)*d+T(i,j)*X(i,j,k)+time(i,j)*2*H*X(i,j,k));

Eq10  (k).. dur(k) =e= sum((i,j)$(ord(j) <> ord(i)),time(i,j)*X(i,j,k));

Eq13  (k).. load(k) =e= sum((i,j)$(ord(i) gt 1 and (ord(i) <> ord(j))),
x(j,i,k)*c(i));

Model exercise /all/;

exercise.optcr=0;

exercise.reslim=14400;

Solve exercise using mip minimizing z;

Display X.l, z.l, dur.l, load.l;
```

Annex 8 – Code implemented for scenario 2

```
Sets
i slaughterhouses
k vehicles /k1*k6/
;
Alias (i,j)
;
Parameters
c(i) quantity of by-products in slaughterhouse i
T(i,j) toll value (€) that must be paid in order to traverse arc ij
dist(i,j) absolute distance (km) of arc ij
time(i,j) needed time to transverse arc ij;
Scalars
Cap capacity of each vehicle (Kgs)/32000/
d transportation cost (€ per Km) /1.15/
v average speed of every truck(km per hour) /80/
H worker salary (€ per hour) /5.54/;
*--------Load all Excel inputs--------*
$ gdxin in.gdx
$ load i
$ load dist T c
$ gdxin
Variables
u(i)      truck position (MTZ variable)
X(i,j,k)  if vehicle k transverses ij
dur(k)    final duration of each truck
load(k)   load of each truck
z         objective variable;
Integer variable
u(i);
time(i,j) = dist (i,j) / v + 0.5;
Binary Variable
X (i,j,k) if vehicle k transverses ij;
Equations
Eq1(j,k)    The depot is always left
Eq2(j,k)    The depot is always visited
```

```
Eq3(j)      Each slaughterhouse is visited once
Eq4(j)      Each slaughterhouse is left once
Eq5(k,i)    Flow continuity respected
Eq6(k)      Truck capacity is respected
Eq7(i,j,k)  Subtours elimination (MTZ)
Eq8(k)      Duration of each truck lower than 8h
Eq11(j)     S33 rejection
Eq12(j)     S33 rejection
objective   Objective function
Eq10(k)     Final duration
Eq13(k) load equation;

Eq1(j,k)$(ord(j) eq 1).. sum((i)$(ord(i) gt 1 and ord(i) <> 34), X(j,i,k)) =L= 1;

Eq2(j,k)$(ord(j) eq 1).. sum((i)$(ord(i) gt 1 and ord(i) <> 34), X(i,j,k)) =L= 1;

Eq3(j)$(ord(j) gt 1 and ord(j) <> 34).. sum((i,k)$(ord(i) <> ord(j) and ord(i) <>
34), X(i,j,k)) =E= 1;

Eq4(j)$(ord(j) gt 1 and ord(j) <> 34).. sum((i,k)$(ord(i) <> ord(j) and ord(j) <>
34), X(j,i,k)) =E= 1;

Eq5(k,i)..  sum(j, x(i,j,k)) =E= sum(j, X(j,i,k));

Eq6(k).. sum((i,j)$(ord(i) gt 1 and (ord(i) <> ord(j))), x(j,i,k)*c(i)) =L= Cap;

Eq7(j,i,k)$(ord(j) gt 1 and ord(i) gt 1 and ord(j) <> ord(i)).. u(j) - u(i) +
card(i)*x(j,i,k) =L= card(i)-1;

Eq8 (k)..sum((i,j)$(ord(i)<>ord(j)),time(i,j)*X(i,j,k))=l=16;

Eq11(j)$(ord(j) eq 34).. sum((i,k)$(ord(i) <> ord(j)), X(i,j,k)) =E= 0;

Eq12(j)$(ord(j) eq 34).. sum((i,k)$(ord(i) <> ord(j)), X(j,i,k)) =E= 0;

Objective.. z =e=
sum((i,j,k),dist(i,j)*X(i,j,k)*d+T(i,j)*X(i,j,k)+time(i,j)*2*H*X(i,j,k));

Eq10 (k).. dur(k) =e= sum((i,j)$(ord(j) <> ord(i)),time(i,j)*X(i,j,k));

Eq13 (k).. load(k) =e= sum((i,j)$(ord(i) gt 1 and (ord(i) <> ord(j))),
x(j,i,k)*c(i));

Model exercise /all/;

exercise.optcr=0;

exercise.reslim=14400;

Solve exercise using mip minimizing z;

Display X.l, z.l, dur.l, load.l;
```

Annex 9 – Route travelled by each truck in each scenario

	SCENARIO 1
K1	s0 – s49 – s48 – s39 – s38 – s36 – s26 – s23 – s35 – s46 – s47 – s0
K2	s0 – s6 – s17 – s11 – s1 – s2 – s3 – s19 – s18 – s9 – s0
K3	s0 – s15 – s8 – s7 – s40 – s41 – s22 – s30 - s0
K4	s0 – s4 – s10 – s32 – s34 – s33 – s31 – s28 – s14 – s20 - s0
K5	s0 – s16 – s25 – s45 – s44 – s50 – s42 – s37 – s24 – s43 – s27 – s29 – s21 – s12 – s5 – s13 – s0
	SCENARIO 2
K1	s0 – s15 – s37 – s42 – s38 – s26 – s24 – s35 – s46 – s47 – s49 – s43 – s27 – s48 – s31 – s14 – s4 – s20 – s0
K2	s0 – s9 – s18 – s1 – s2 – s3 – s19 – s11 – s6 – s17 – s0
K3	s0 – s7 – s30 – s25 – s45 – s50 – s44 – s36 – s23 – s39 – s22 – s41 – s40 – s16 – s8 – s0
K4	s0 – s28 – s21 – s29 – s34 – s32 – s10 – s12 – s5 – s13 - s0
	SCENARIO 3
K1	s0 – s4 – s20 – s12 – s5 – s13 – S0
K2	s0 – s6 – s17 – s11 – s18 – s3 – s2 – s1 – s19 – s0
K3	s0 – S15 – s14 – s10 – s7 – s16 – s8 – s0

Annex 10 – GAMS model statistics

Model statistics	Scenario 1	Scenario 2	Scenario 3
Number of single equations	30 185	30 185	2 076
Number of single variables	31 287	31 287	2 236
Number of discrete variables	31 262	31 262	2 225
Best possible value (€)	1 390.21	1 304.41	751.29
Relative gap (%)	56	55	15