Optimal Sustainable Distribution Network: The case of Nespresso

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Declaração

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

Declaration

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

Abstract

The consumption of coffee in capsules has grown in recent years due to the convenience it offers to consumers. This factor combined with the growth in the commercialisation of this type of product through the e-commerce channel and the requirement from consumers to obtain the products as quickly as possible, has challenged Nespresso to have an optimised supply chain.

Therefore, this project explores this need and focuses on the design and planning of the Nespresso distribution network. Furthermore, the concept of sustainability, and its three dimensions: economic, environmental and social, will be integrated into the definition of the different entities in the supply chain, so these objectives are studied.

Firstly, the case study is presented, in which several aspects related to Nespresso are highlighted, such as its supply chain, sustainability policies, the constitution of its coffee capsules, the collection and recycling process, and more specifically, the origin of this project and which part of the supply chain will be analysed. Afterwards, a literature review is performed on the most relevant concepts for the problem, and the model that will serve as the basis for the case study is presented. This model assesses the three dimensions of sustainability and enables the analysis of demand uncertainty.

In addition, data of the case study are presented. With the application of the model to Nespresso, an analysis of the results is prepared, and some recommendations are listed for a sustainable distribution networks that perform well in all three dimensions.

Keywords: Coffee Capsules, Sustainability, Forward Logistics, Design and Planning, Distribution Network

Resumo

O consumo de café em cápsulas tem crescido nos últimos anos devido à conveniência que oferece aos consumidores. Este fator aliado ao crescimento da comercialização deste tipo de produtos através do canal e-commerce e à exigência por parte dos consumidores em obter os produtos o mais rápido possível, desafiou a Nespresso a ter uma cadeia de abastecimento otimizada.

Portanto, este projeto explora esta necessidade e foca-se no projeto e planeamento da rede de distribuição da Nespresso. Além disso, o conceito de sustentabilidade, e os seus três pilares: económico, ambiental e social, serão integrados na definição das diferentes entidades da cadeia de abastecimento, pelo que estes objetivos são estudados.

Primeiramente, é apresentado o caso de estudo, em que são realçados diversos aspetos relacionados com a Nespresso, tais como: a sua cadeia de abastecimento, as políticas de sustentabilidade, a constituição da sua cápsula de café, o processo de recolha e reciclagem, e mais em específico, a origem deste projeto e que parte da cadeia de abastecimento será analisada. Posteriormente, é realizada uma revisão bibliográfica sobre os conceitos mais relevantes para o problema, e é apresentado o modelo que servirá de base para o caso de estudo. Este modelo avalia as três dimensões de sustentabilidade e possibilita a análise da incerteza da procura.

Adicionalmente, são apresentados dados relativos ao caso de estudo. Com a aplicação do modelo à Nespresso, é elaborada uma análise de resultados, e são enumeradas algumas recomendações de redes de distribuição sustentáveis que apresentam bons desempenhos nas três dimensões.

Palavras-chave: Cápsulas de Café, Sustentabilidade, Logística Direta, Desenho e Planeamento, Rede de Distribuição

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Acronyms

ADG: Annual Demand Growth

AICC: Associação Industrial e Comercial do Café

ASI: Aluminium Stewardship Initiative

CAGR: Capsule Annual Growth Rate

CGRPO: Capsule Growth Rate per Order

CLSC: Closed Loop Supply Chain

CLSCM: Closed Loop Supply Chain Management

CO_2: Carbon Dioxide

CSR: Corporate Social Responsibility

FL: Forward Logistics

FLN: Forward Logistics Network

GDP: Gross Domestic Product

GP: Goal Programming

GSCM: Green Supply Chain Management

KDP: Keurig Dr Pepper

LCA: Life Cycle Assessment

MILP: Mixed Integer Linear Programming

MINLP: Mixed Integer Nonlinear Programming

MOMILP: Multi-Objective Mixed Integer Programming

MU: Monetary Units

NPV: Net Present Value

OFC: Order Fulfilment Centre

RL: Reverse Logistics

RLN: Reverse Logistics Network

SC: Supply Chain

SCM: Supply Chain Management

SDGs: Sustainable Development Goals

SRG: Sustainability Reporting Guidelines

SSC: Sustainable Supply Chain

SSCM: Sustainable Supply Chain Management

TBL or 3BL: Triple Bottom Line

UR: Unemployment Rate

USA: United States of America

WCED: World Commission on Environment and Development

1. Introduction

1.1. Contextualisation

The way in which coffee is consumed worldwide was radically changed when, more than 40 years ago, John Sylvan created K-Cup, the first coffee capsule (Independent, 2020). Since then, the consumption of coffee using capsules has grown due to two factors. On one hand, this growth is due to the improvement in both the equipment/machines available and the quality that coffee in capsules provides, something felt by consumers. On the other hand, as the quality of coffee in capsules is already similar to the quality experienced by consumers in the Horeca channel, and due to macroeconomic and convenience factors, coffee consumption is now made at home (Notícias, 2020).

According to the Nielsen consultancy, the consumption of coffee through the use of capsules already assumed, in 2016, a dominant role in relation to the other forms of consumption, since they represented more than 60% of the total market of the category (Hiper Super, 2020). More recently, according to data from 2018, of the total coffee sold at retail level, the domestic market for roasted coffee is equivalent to 82%. The latter includes the consumption of coffee using capsules, which represent 79% of roasted coffee (Notícias, 2020). Regarding coffee capsule sales, in 2018, an increase of 9% over the previous year was recorded (Notícias, 2020).

Despite the high growth in consumption of coffee in capsules, the secretary general of the AICC (*Associação Industrial e Comercial do Café*), Cláudia Pimentel, states that due to the growth in environmental awareness, a slowdown in sales of coffee in capsules could be noted (Notícias, 2020).

Taking into account these data on the growth over the years of coffee capsule consumption, and the possible slowing down of this growth due to environmental and sustainable considerations, companies in this industry have been looking at their supply chains with a focus on achieving better economic, environmental and social supply chains.

In this context, the present work emerges, which aims to analyse, in terms of sustainability, the current Nespresso distribution chain, as well as to support possible changes in this network in order to provide different performances, in each sustainability dimensions.

1.2. Objectives

This thesis aims to present the relevance of the problem identified in the previous section through the following objectives:

- Characterise the problem and consequently the motivation for this project;
- Characterise Nespresso, in terms of supply chain and sustainability policies applied;

- Highlighting the challenges in the Nespresso Supply Chain;
- Introducing the current Nespresso distribution Network;
- Elaborate a literature review to the most relevant concepts such as: supply chain, sustainable supply chain, supply chain logistics and present optimization models related to the design and planning of sustainable supply chains;
- Choosing and adapting an optimization model to apply to the problem under study;
- Definition of the data and assumptions to apply in the model;
- Application of the model to Nespresso case-study and analyse the different networks obtained;
- Developing sustainable recommendations of Nespresso distribution networks.

1.3. Research Methodology

This subsection presents the methodology used to address the problem under study. It is divided into 5 parts, as can be seen in Figure 1, and are described below.

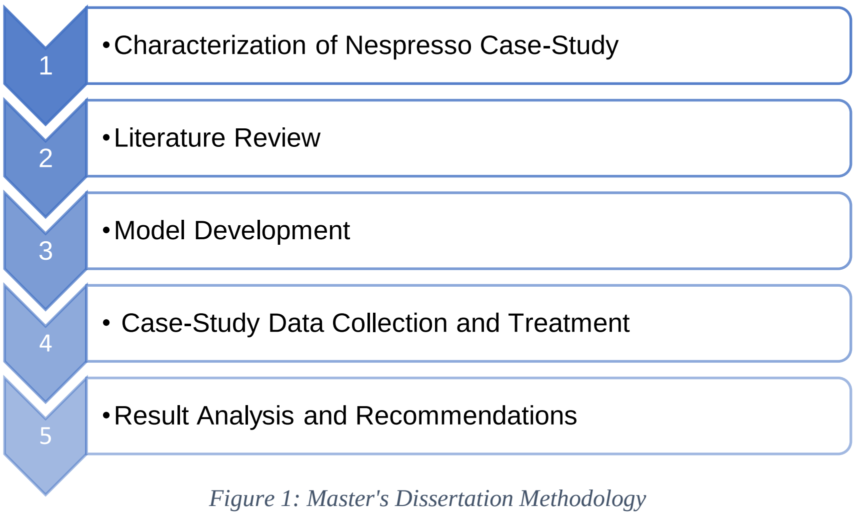


Figure 1: Master's Dissertation Methodology

1. <u>Characterization of Nespresso Case-Study:</u> This phase describes the Nespresso case study in which the history, current network and sustainability policies of the company are detailed. In addition, the main characteristics of the Nespresso coffee are presented. Finally, three more companies are characterized, two of them being international players and on is a Portuguese player. The characteristics of these companies are compared with those of Nespresso.
2. <u>Literature Review:</u> In this second phase a literature review of the most relevant concepts such as supply chain, sustainable supply chain and supply chain logistics is performed. Finally, optimization models are presented that aim at the design and planning of supply chains.
3. <u>Model development and Application:</u> In this third phase, the supply chain optimization model is developed, being presented all the objective functions and constraints considered.

4. Case-Study Data Collection and Treatment: This step corresponds to the collection of data relevant to the problem that will be applied later in the model developed. The data collected are related to the objectives of sustainability, and therefore data on the three pillars are collected. Through the data, it will be possible to define the necessary assumptions.
5. Result Analysis and Recommendations: In this final phase, the results obtained in the different scenarios considered are analysed and, based on the sustainability from each scenario, a set of good sustainability solutions are presented and discussed.

1.4. Dissertation Structure

This Dissertation Project consists of the following eight chapters:

- Chapter 1 – Introduction: This chapter briefly describes the problem, highlighting the motivation for the existence of this Dissertation Project. Afterwards, the methodology, the objectives of the project and its structure are presented.
- Chapter 2 – The Case Study: In the second chapter, the history of Nespresso and its current supply chain are presented. Then, there is a description of the sustainability policies applied in the company, the composition of the used capsules and the collection methods that the company make available, as well as the existing steps in the recycling of coffee capsules. In addition, three companies that dominate the national or international capsule coffee market are presented, and the challenges for companies in this market are outlined.
- Chapter 3 – Literature Review: In this chapter are explored the definitions given by several authors, about the most relevant concepts that are present in the problem presented. Further on, a set of models are presented that describe the design and planning of the supply chain, considering forward logistics or the closed loop supply chain, highlighting the sustainability dimensions present in these models.
- Chapter 4 – Model: The model and its mathematical formulation are characterised.
- Chapter 5 – Case Study: Data Collection and Treatment: This chapter presents the data collected as well as some assumptions made to deal with the complexity of the problem.
- Chapter 6 – Case Study Results: The sixth chapter presents the results obtained according to the optimisation of each of the sustainability dimensions, and multi-objective analyses are prepared to assess networks that perform well in more than one sustainability dimension. Also, in this chapter several scenarios are elaborated to evaluate the uncertainty associated to Nespresso's demand, in the time period considered.
- Chapter 7 – Recommendations: This chapter provides some recommendations based on the networks and analyses developed in the previous chapter.
- Chapter 8 – Conclusions and Future Work: In this last chapter, the conclusions of the study are presented as well as possible consideration for a future work.

2. The Case Study

This chapter introduces the case study, Nespresso Supply Chain, and is organized in 8 sections. In the first two sections, the history of Nespresso and its supply chain are presented. The following two sections, 2.3 and 2.4, describe the case study and the Nespresso OFC (Order Fulfilment Center) network in detail, respectively. Subsequently, section 2.5 identifies the sustainability policies and strategies that Nespresso adopts. Section 2.6 looks at the characteristics of Nespresso's coffee capsules and the collection processes and recycling system that the company has. Section 2.7 describes the characteristics of two other key international players, one American and one European and one Portuguese player, and highlights the differences and similarities between each of these and the company under study. Finally, the chapter concludes with section 2.8, in which the main challenges, in terms of the supply chain, of the Nespresso is characterised.

2.1. Nespresso

Nespresso has revolutionised the way coffee is drunk, through the variety of aromas in its capsules, the modern design of its machines and the creation of Nespresso Boutiques. All these factors, the continuous innovation and highest quality, have captured the attention of consumers and coffee lovers around the world (Nestlé Nespresso, 2015).

In 1970, the Nestlé group, through the Research and Development department, received the mission of developing a system to make an espresso coffee that resembled the best Italian coffees in terms of quality. Thus, a revolutionary machine was created using hermetically sealed coffee capsules (Reis, Martins, Pinto, Pereira, & Duarte, 2012). Six years later, the Nestlé group patented the process (Mundo das Marcas, 2019).

However, it was only in 1986 that, in partnership with the manufacturer Turmix, the Nespresso brand was created in the city of Vevey, Switzerland. At this time, only 4 coffee varieties and one machine model were available, and the products were only available for offices in Switzerland, Italy and Japan (Nestlé Corporate Communication, 2016). From that year forward, there were five phases of growth and innovation until today, as can be seen in Figure 2.

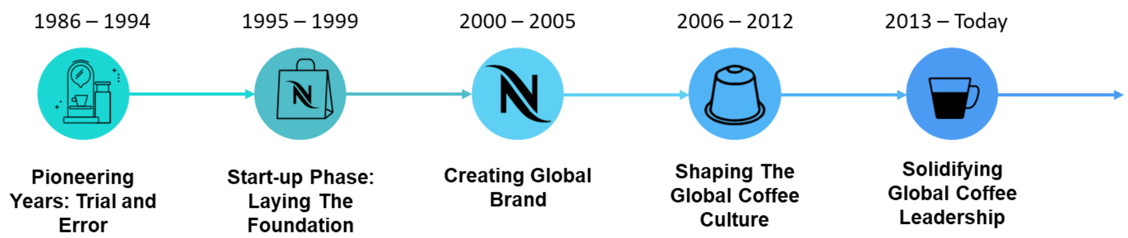


Figure 2: Nespresso's Five Phases of Growth and Innovation, adapted form Nestlé Corporate Communication, 2016

The phase *Pioneering Years: Trial and Error* corresponds to the brand's creation and its introduction on the market. During this phase, the Nespresso Club concept was launched and in

1991 the first Nespresso capsule recycling program was created in Switzerland (Nestlé Corporate Communication, 2016).

The second phase is characterised by expansion both in terms of coffee variety and machines, for both the business-to-business (B2B) and business-to-consumers (B2C) markets, being launched, in 1998, the e-commerce website, which allows on-line ordering 24 hours a day and 7 days a week (Nestlé Corporate Communication, 2016).

Over the years and with the success of the brand, the machines began to have a more modern design and were adding new aromas to the existing range, many of them being limited editions, since they come from unusual places, resulting in the phase *Creating Global Brand* (Nestlé Corporate Communication, 2016). In 2000, the first Nespresso Boutique was opened in Paris and *Nespresso Concept Machine* broke the sales record, culminating in an expansion into a new capsule production centre in Orbe, Switzerland. The construction of this new centre was primarily aimed at increasing production capacity in order to anticipate increased demand and online ordering (Mundo das Marcas, 2019). Also, at this phase, the Nespresso AAA Sustainable Quality Program was created (Nestlé Corporate Communication, 2016).

On fourth phase, *Shaping The Global Coffee Culture,* a new production and distribution centre, in Avenches, Switzerland, started operating, and in the final year of this phase, the outlined target of 75% capsule recycling capacity utilisation has been achieved (Nestlé Corporate Communication, 2016).

In the *Solidifying Global Coffee Leadership phase,* the VertuoLine capsule was created to satisfy the American and Asian markets, since the consumption of coffee made by these markets are mostly made through large cops, rather than espresso (Nestlé Corporate Communication, 2016).

Currently, in addition to the existence of the most diverse models of machines and the most diverse aromas, there are about 1500 points of delivery and collection throughout in Portugal, as well as 23 Nespresso Boutiques. Worldwide there are 808 Nespresso Boutiques, 473 of which are located in Europe, 180 in Africa and Oceania as a whole, 155 in the American continent, 58 of which are in the USA.

For the customers to get the Nespresso coffee they will have only two solutions, they can order via internet, mobile app and / or phone call, or simply go to the Boutiques. Unlike the other brands on the market, Nespresso coffee is not found in any reseller (Nespresso, 2019c). However, in the case of machines, they can be found for sale at retailers.

One important concern of Nespresso is its global competitiveness and continuous improvement while considering sustainability goals (Aus et al., 2017). To guarantee so the Nespresso's global supply centre was established in Portugal in 2019. This operational and competence centre has the responsibility for enabling the improvement of Nespresso's supply chain processes and practices. More precisely, all flows in the supply chain are controlled and supply chain best practices are constantly being created, analysed and applied throughout the supply chain (Moderna, 2018).

2.2. Nespresso Supply Chain

Nespresso's supply chain includes different entities, from the coffee producers to the end consumers, and therefore different relationships between entities (Figure 3).

Figure 3: Nespresso's Supply Chain

Starting with the suppliers, Nespresso works with over 70 000 coffee suppliers around the world and there is a direct relationship between them and Nespresso, as coffee is bought directly without intermediaries. To ensure the quality of coffee, Nespresso, through the Nespresso AAA Sustainable Quality programme, helps to improve productivity and social aspects, and promotes the reduction of environmental impacts (Moderna, 2018).

Once the coffee grains have been produced, they are transported by boat to the port, and then shipped by rail to the Nespresso industrial complex in Switzerland, which consists of 3 factories where the coffee blends are made and where the coffee capsules are produced. At the factory in Avenches the Original capsules are produced, at the Romont factory the VertuoLine capsules and at the Orbe factory the B2B capsules (Moderna, 2018).

The products are then transported to the International Distribution Centre located in Avenches. In this unit, there is only a capacity to store, approximately, 50 000 pallets, a low number, being justified by the objective of maintaining the maximum freshness of the products, and consequently a stock capable of supporting a few days of demand. The capsules then go to the Order Fulfilment Centre (OFC), centres that prepare the orders, and which are the responsibility of logistics operators with whom Nespresso has a contract (Moderna, 2018).

Although OFCs are responsible for the order's preparation from different regions, they are not independent, as they are part of the Nespresso supply chain. As such, each OFC has a responsible person, the Head of Supply Chain in that market, who responds to the Market Head Global, the person responsible for the entire Supply Chain (Moderna, 2018).

A similar process exists for coffee machines and accessories, however, these products go directly to the International Distribution Centre located in Brussels, where they are stored and shipped to the different OFCs (Moderna, 2018).

In the OFCs with the highest order volume there is the pick to light system, which is used in the preparation of the order, increasing the accuracy in this process. In addition, a technology, called cubing, is also used due to the existence of products with different sizes, which in combination with the previous system, helps to build the orders in a cube shape, and which makes the process more efficient (Moderna, 2018). In OFCs located in markets with smaller demand, the preparation of orders is done without the support of these systems, but instead follows a similar manual operation/process.

In 2018, there were approximately 130 OFCs covering 50 markets worldwide, which is equivalent to 60/70 countries (Moderna, 2018).

At the destination level of the products, once they leave the OFCs, there are two possibilities, either to go to the final consumer in the form of orders, or to go to Nespresso Boutiques, still on pallets. Most of the Nespresso's business is the preparation of orders (Moderna, 2018). According to the market and customer culture, online sales are more or less representative of global demand compared to sales in Nespresso Boutiques.

Nespresso's supply chain is organised according to a push-pull system, with the push-pull boundary at OFCs. From suppliers to OFCs, the aim is to push products manufactured to OFCs. The option of this system is justified by the objective of delivering the orders in the shortest possible time. Therefore, each market's Supply Chain team prepares annual, monthly and weekly demand forecasts and transmits them to the OFC of the respective market. With this data, it is decided which products and which quantities need to be transported to that OFC in order to maintain an adequate inventory level. In the second part of the Nespresso supply chain, from OFCs to markets/customers, the products are shipped based on customers' orders, so the system used is pull, since it is the customers who initiate this flow. By mixing these two systems, in different parts of the supply chain, Nespresso has full visibility throughout the supply chain, and can thus describe the entire flow of each capsule (Moderna, 2018).

One of the main concerns at Nespresso is to guarantee high levels of service with high quality of products in a sustainable way (Aus et al., 2017).

2.3. Products and Sustainability at Nespresso

Nespresso's value chain can be divided into 8 phases, as identified in Figure 4. Firstly, there is the phase of *Growing and Harvesting Coffee*. In terms of quality specifications, Nespresso ensures that the best terrain is chosen based on the coffee's profiles. In addition, harvesting is done manually, without the use of machines, since the coffee is only harvested if it is perfectly ripe. Coffee grades are subsequently transported – *Transportation* $_1$ - from the place of harvest to Nespresso facilities. After, there is the *Green Coffee Process*, where a wet method is used to enhance the coffee's aromas. The fourth phase is *Blending, Roasting and Grinding*. In order to maintain the quality that characterises the Nespresso brand, a very strict selection is made of the densest coffee beans, which do not have any kind of defect. Furthermore, each Grand Cru (coffee varieties) has a unique blend, a roasting recipe and specific grinding size. After the previous stage, the coffee capsules are filled – *Filling Coffee Capsules* – in a controlled atmosphere in order to preserve the coffee freshness. When the coffee capsules reach the consumers, through *Transportation* $_2$, the coffee is extracted into the cup – *Extraction in Cup* - at high pressure, in which energy savings are guaranteed. Finally, there is the *Recycling* phase, in which all the capsules elements (aluminium and coffee grains) are treated in such a way as to gain a new life, allowing a circular value chain (Creating Shared Value For More Than 10 Years, Nespresso, 2019, n.d.)

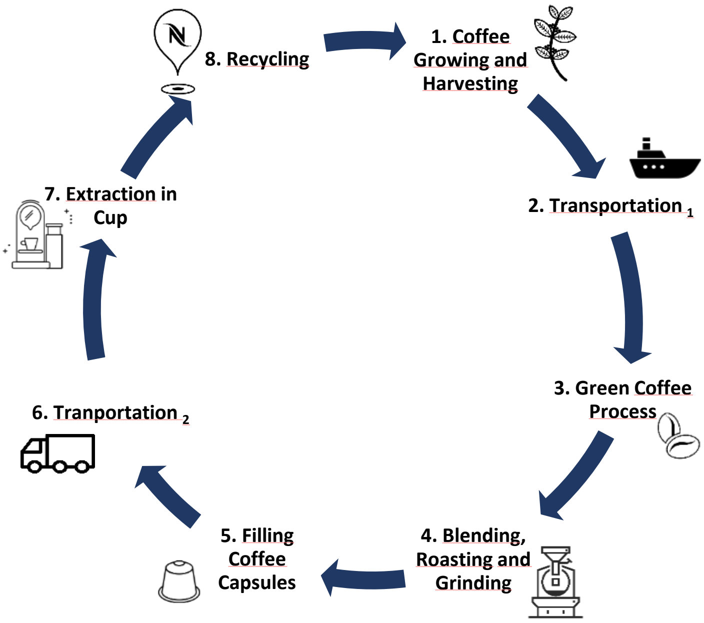


Figure 4: Nespresso's Value Chain, adapted from Creating Shared Value For More Than 10 Years, Nespresso, 2019

Nespresso's approach to sustainability is through its "*The Positive Cup*" strategy. Thus, they believe that, by 2020, they can turn every cup of Nespresso coffee into a positive cup. In other words, in addition to providing a moment of pleasure, coffee can also help restore, replenish and revitalise all the communities involved in its production. Thus, *The Positive Cup* has as its purpose three audacious goals, and these goals have one factor in common: 100%. The first is related to the main raw material, coffee, the second to the capsule's constituent material, aluminium and the third to the climate. The targets for 2020 are as follows (Aus et al., 2017).

- Coffee from all regions of the world is of 100% sustainable origin;
- All (100%) of the aluminium is managed in a sustainable way;
- All (100%) operations are carbon efficient for the environment.

These targets were set since, after analysis of the carbon footprint of a Nespresso coffee cup, it was found that 97% of the carbon footprint comes from activities that occur upstream and downstream of its main operations (e.g., from coffee producers and consumers). Figure 5 shows the stages that contribute to the carbon footprint and the respective percentages of CO_2 eq. per Nespresso's cup. These data are from 2013 and were obtained in the analysis performed by Quantis using the LCA (Life Cycle Assessment) tool. As a result, only 3% of the total carbon footprint derives from roasting, grinding and production operations, which are considered by Nespresso as the main operations for producing coffee capsules. Among the remaining phases, the phase that most contribute to the carbon footprint is Consumer Use (48%), followed by Coffee Farming (19%) and Production and Packaging (18%). With the lowest contribution are the Distribution (8%) and End-of-life (5%) (Nestlé Nespresso, 2018). With these results, there are opportunities to act in areas not controlled by Nespresso, but on which they have significant dependence and impacts (Aus et al., 2017).

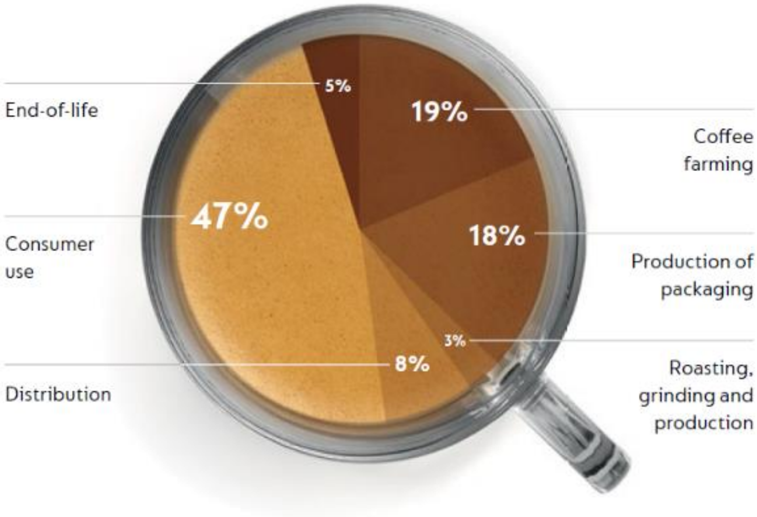


Figure 5: Carbon Footprint assessment of a cup of Nespresso, expressed in % CO2 eq. per cup, retrieved from Nestlé Nespresso, 2018

With *The Positive Cup* strategy, Nespresso believes it is meeting 11 of the 17 Sustainable Development Goals (*1 – No Poverty; 2 - Zero Hunger; 4 - Quality Education; 5 - Gender Equality; 6 - Clean Water and Sanitation; 8 - Decent Work and Economic Growth; 12 - Responsible Consumption and Production; 13 - Climate Action; 15 – Life on Land; 16 - Peace, Justice and Strong Institutions; 17 - Partnerships*) (Aus et al., 2017).

While goals 8 and 12 of the SDGs define the direction of Nespresso's role as a consumer goods producer, the remaining SDGs are related to the Nespresso supply chain and business principles.

The three targets for 2020 set by Nespresso, referred to above, will be described in more detail in the next subsections.

2.3.1. 100% Sustainable Coffee

Only 1% to 2% of the coffee produced worldwide meets Nespresso quality standards. As such, Nespresso is highly dependent on producers, forcing it to ensure the supply of high quality coffee by supporting producers. The Nespresso AAA Sustainable Quality programme was set up in 2003 together with the Rainforest Alliance to work with farmers and other partners to strengthen coffee-growing regions in the face of economic uncertainty and climate change. The 3 pillars of the Nespresso AAA Sustainable Quality programme are a firm commitment to quality, a practical support for productivity and a clear focus on social and environmental sustainability. The first pillar is based on compensation with price premiums, whenever the coffees produced are approved with the high quality required by Nespresso. The quality of the coffee derives from several factors such as harvesting and processing after harvesting. These price premiums are paid to the AAA farmers (farmers who have joined to the programme) and consist of a payment of 30% to 40% above the standard market price (Nespresso, 2019a).The second pillar involves the management of the entire production process, from the development of sustainable practices to cost management, which provides long-term stability in producers' profits and greater productive capacity. Finally, the third pillar is based on social and environmental factors, i.e. the preservation and protection of biodiversity, the management of resources such as water and the working conditions of producers (Aus et al., 2017).

2.3.2. 100% Sustainable Aluminium

With the aim of maintaining the freshness and quality of coffee, and protecting the product from light, humidity and oxygen, Nespresso claims that the best material that can be used is Aluminium. Exposure to one of these 3 factors would result in a decrease in coffee quality, which would result in more waste.

In addition to these qualities, aluminium is a material that can be infinitely recycled, which translates into the statement that 75% of the aluminium already produced is still in use today.

In order to promote the sustainable production and circular economy of aluminium, Nespresso invest in an effective recycling system at scale, committing to creating a sustainable aluminium supply chain (Aus et al., 2017).

2.3.3. 100% Climate Efficient Operations

The quantity and quality of the coffee produced is very dependent on the existence of a stable climate. Nespresso obtains its coffee in several regions of the world and these are increasingly vulnerable to the effects of climate change. To minimize possible damage, Nespresso is working with farmers to build a resilience mechanism in agricultural landscapes.

Nespresso recognizes the carbon footprint every time a cup of coffee is consumed. Knowing this, through the Life Cycle Assessment tool, it identifies and quantifies the main environmental impacts caused, as outlined above and shown in Figure 5. Furthermore, this tool is used to support Nespresso's decisions, obtaining the best environmental choice. LCA is used to assess the environmental performance of a given product. Under this tool, Nespresso has chosen to base its decisions on the outcome of the carbon indicator, and has provided conservative assumptions for calculating environmental impact, based on Nestlé Group policies.

The two main measures until 2020 are to reduce the carbon footprint of a cup of coffee by 28% compared to 2009 and to strengthen the resilience of the coffee landscape by planting 5 million trees (Aus et al., n.d., The Positive Cup). The first objective will be accomplished by improving the energy efficiency and the use of recyclable in their machines, using renewable energy in business operations, promoting good farming practices, moving towards the use of new low-carbon aluminium *Aluminium Stewardship Initiative (ASI)* and increasing the number of recycle capsules (Nestlé Nespresso, 2018).

2.4. Coffee Capsules

Nespresso capsules are made of aluminium only due to the above-mentioned characteristics. However, Nespresso requires its capsules to contain a certain grade of aluminium, but there is little such grade. Thus, Nespresso states that in order to achieve the desired aluminium grade, aluminium from recycled Nespresso capsules should be used, provided it is economically and environmentally viable (Nespresso, 2019b).

Despite these characteristics of aluminium, it is not in contact with coffee due to a food grade layer. This makes it impossible for the aluminium to migrate to the capsule content during coffee preparation (Figure 6) (Aus et al., 2017).

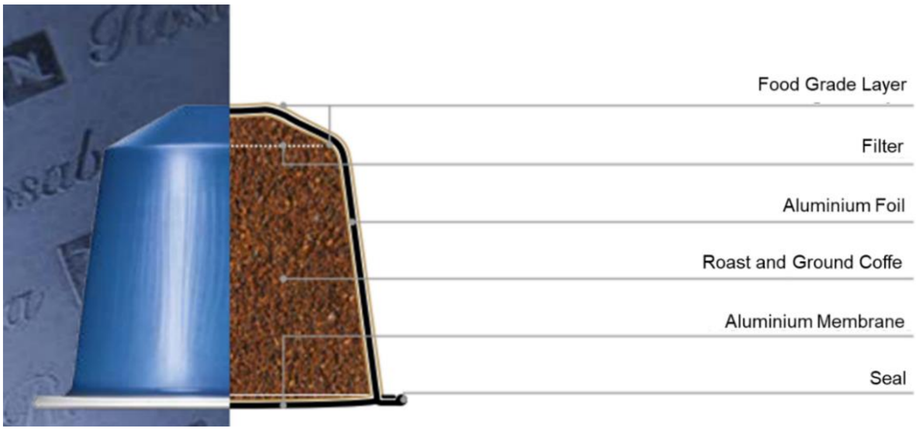


Figure 6: Constitution of the Nespresso Capsule, adapted from Aus et al., n.a., The Positive Cup

2.4.1. Collection of Coffee Capsules

Nespresso is committed to researching and developing the process of collecting and recycling coffee capsules. As such, Nespresso seeks to provide all their customers with the most convenient solution for each of them.

Nespresso's customers have three types of capsule collection at their disposal. Firstly, they can deliver the already used capsules to Nespresso recycling points, of which there are already more than 200 in Portugal. Alternatively, they can deliver to a Nespresso Boutique, which is closer to the customer, or, when the customer receives their order at home, they can return used capsules to their delivery partners in their own Nespresso recycling bag (Nespresso, 2019b).

Nespresso does not offer any kind of benefit to their customers as they are delivering the used capsules to be later recycled. Nespresso believes that consumers' awareness of environmental sustainability, by itself, serves as a motivation for the recycling of capsules (Nespresso, 2019d). Nespresso only invests in the use of education and awareness campaigns to increase the number of conscientious consumers and in this way, look for more sustainable products. In addition, Nespresso assumes all the costs that are inherent to the collection and recycling of capsules.

2.4.2. Recycling of coffee capsules

The aluminium supply chain can be divided into two phases: primary production and manufacturing and recycling, identified in Figure 7. In the first phase, primary production and manufacturing, bauxite is extracted (a mineral mixture of aluminium oxides and hydroxides), which is the raw material used in the production of aluminium. With the Bayer process, it is possible to extract alumina from bauxite, and later, by electrolysis, it is possible to obtain aluminium. At this stage aluminium is made available to the other companies, and then moulded according to the desired purpose. In the second phase, especially under the Nespresso brand, the capsules are formed, which after use go into the recycling process and then re-enter the capsule production cycle (Aus et al., 2017).

Nespresso's recycling process consists of 5 steps. First, the capsules, after being collected through the company's dedicated recycling programme, are sent to the recycling centre. There, in order to separate the remaining coffee grains from aluminium, the capsules are destroyed. While the coffee grains are transformed into either renewable energy or nutrient-rich compounds, the capsules are melted to remove any other materials they may still contain. When all these materials are removed and only aluminium remains, it is also melted to be recycled. This aluminium, by being recycled, can give life to new objects such as computers, cars or new capsules (Nespresso, 2019b).

Although professional and household capsules have the same recycling process, Nespresso separates them immediately after they arrive at the recycling centre for statistical purposes. In 2018, Nespresso reported a 15% recycling rate in Portugal, with a 2020 target of 25% recycling of used capsules in the country (Ambiente Magazine, 2019).

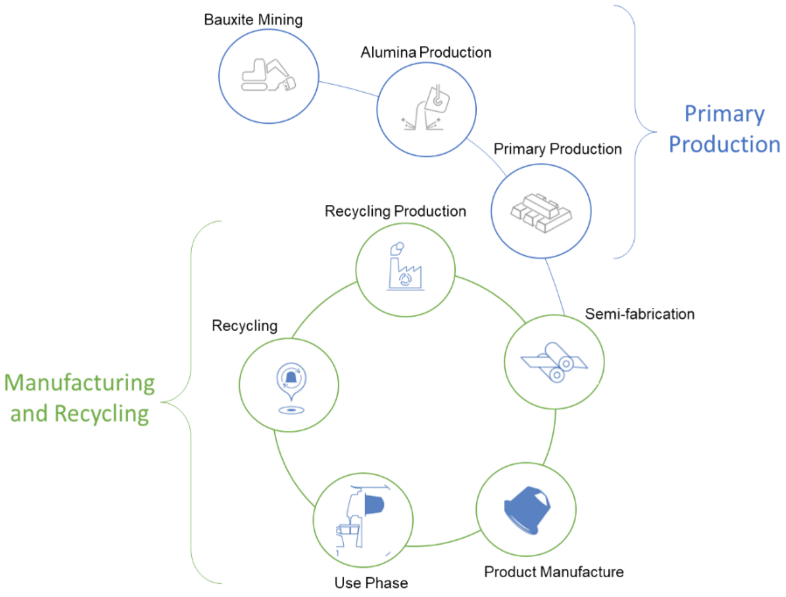


Figure 7: Aluminium Supply Chain, Aus et al., n.a., The Positive Cup

2.5. Key Players in the Coffee Capsules Market

In order to compare some characteristics of Nespresso described above with others, two key players, that dominate the international capsule coffee market, were selected: Keurig Dr Pepper (KDP), with Green Mountain Coffee Roaster and Luigi Lavazza SPA, with the Lavazza brand (Market Watch, 2019); and also Delta Cafés, with the Delta Q brand, which was considered the best coffee brand in Portugal, according to the study prepared by Global RepScore Pulse in 2019 (Máquinas de Café, 2019). International brands are selected due to the market in which they operate and their sales volume, which in each of these companies is around billions of euros.

Due to the size of these companies, it is intended to compare their supply chain with Nespresso's in the following sections, highlighting the differences and also the aspects on which they are similar.

2.5.1. Green Mountain Coffee Roaster

The USA company, Keurig Dr Pepper, was founded, in 2018, through the merger of Keurig Green Mountain and Dr Pepper Snapple Group, and is currently the leading company in the USA market, with annual revenues in excess of $11 billion (KDP, 2019).

Green Mountain Coffee Roaster's operations are coordinated from Waterbury, located in Vermont, by headquarters. In addition, it has a distribution centre network located in Connecticut, Massachusetts, Upstate New York and Maine. These distribution centres are strategically placed so that most customers are located within a two-hour radius. In order to complement this network, Green Mountain Coffee Roaster has partnerships with logistics operators, which support the remaining customers, that cannot be supported by the other network (Green Mountain Coffee Roasters, 2006).

2.5.1.1. Green Mountain Coffee Roaster vs Nespresso

Comparing the supply chain characteristics of Green Mountain Coffee Roaster (GMCR) with those of Nespresso, and focusing on the supply chain entities responsible for distributing and delivering products to consumers, it can be noted that while Nespresso delivers the full responsibility to the logistics operators, the large majority of GMCR are responsible for this distribution.

In this way, GMCR, by having its own distribution centres, achieves greater control over the logistical process, guarantees better quality both in the products and in the processes involved in preparing orders. However, as GMRC has few distribution centres of its own, and these are all located in the eastern zone of the United States of America, the remaining areas of the countries in which the company is inserted are supplied by logistics operators, although the volume of sales is significantly lower.

Therefore, it can be concluded that since most of GMRC's demand is centralised in the same area where the company owns the distribution centres, it is not so dependent on the logistics operators as Nespresso.

2.5.2. Lavazza

The Italian company Luigi Lavazza S.P.A was founded, in 1895, by Luigi Lavazza, and is currently a company that manufactures various coffee products. Under the Lavazza brand, consumers find a coffee capsule known worldwide for its excellence in Italian coffee (Lavazza, 2019). Lavazza's net revenues in 2018 were 1.87 billion euros, an increase of 9.3% compared with the previous year (Lavazza, 2018).

Lavazza is a company that operates in more than 90 countries, and therefore has a complex supply chain. It has 10 factories spread over 7 countries and has several subsidiary companies in 11 countries, which are essentially in charge of the distribution and marketing of coffee products and their machines (Lavazza, 2018). In addition, there are several distributors in the countries where Lavazza is located (Lavazza, 2020).

2.5.2.1. Lavazza vs Nespresso

Analysing both Nespresso and Lavazza supply chain, it can be stated that both attribute responsibility for distribution to other companies, namely logistics operators. On the other hand, Lavazza, by having subsidiary companies, guarantees specialisation in the various operations and greater control and operational efficiency.

Considering that Lavazza has subsidiaries in the countries with the highest representation in total demand, it manages to reduce its dependence on logistics operators.

2.5.3. Delta Q

Delta Cafés, Portuguese company, was founded by Manuel Rui Azinhais Nabeiro in 1961, however, in order to reinforce growth, the Delta Q brand was created in 2007 to produce coffee capsules, which are exclusive and patented (Marcas que Marcam, 2019).

Delta Cafés is always committed to innovation and quality, based on the development of new products that are the most suitable for the target market. Due to the social responsibility strategy that it incorporates, it gave rise to the *Human Face* system, which is characterized by continuous innovation, dialogue and responsible entrepreneurship (Delta Cafés, 2019).

Delta has operations in 48 countries, with 30% of sales coming from international markets. However, it only has direct operations in 8 countries: Portugal, France, Luxembourg, Spain, Switzerland, Brazil, Angola and China. Delta Cafés' growth is largely due to its positive reception in the different markets of Delta Q, which is valued for its diversity of coffee (Mundo, 2018). Regarding the distribution of the products, Delta has cooperation of distributors from several countries (Delta Cafés, 2020).

2.5.3.1. *Delta Q vs Nespresso*

Compared to Nespresso, Delta is present in several countries and has contracts with logistics operators which are responsible for the distribution of the product. Although Delta is less present worldwide compared to Nespresso, the supply chains of these companies are quite similar, so both face similar challenges, such as less control over order preparation and distribution.

The existence of contracts with logistics operators results from the need for companies such as Nespresso, Lavazza and Delta to concentrate on the activities that generate the greatest value, i.e. the production of coffee capsules. In this way, these companies hire logistics operators, since they already have the knowledge and experience in this sector of activity, which may mean the existence of a lower cost because there is the use of economies of scale, since these companies work with several other companies that need this service.

2.6. Challenges in Coffee Capsules Market

As noted above, the capsule coffee market has been driven by consumer preference for a single dose of coffee. This growth is most evident in the North American regions and in Europe (Mordor Intelligence, 2019).

This factor added to the growing commercialization of products via the e-commerce channel, and the continuous pressure from consumers to receive their products in the shortest possible time, has caused companies to be increasingly concerned about the geographic layout of their supply chain, always trying to locate themselves as close to their markets as possible. This has been the case for all companies in the B2C market, and more specifically for the coffee market.

Nespresso has felt the impact of e-commerce growth, as the growth of this channel has led to an increase in costs proportionate to profits. This is happening since the company always aims to deliver orders in most markets within 24 hours. This led to a challenge in Nespresso that is to optimise their Supply Chain.

2.7. Nespresso Supply Chain Challenge

As stated, given the growing concern of companies to optimise their supply chains, and the emergence of internet commerce, known as e-commerce, companies are making adjustments in their supply chains in order to continue to meet the needs of their consumers at a minimum cost and in a sustainable form.

In order for Nespresso to be closer to customers, offering greater speed and agility, the current goal is to achieve a network of OFCs at the lowest possible cost without compromising customer satisfaction, i.e. without changing the conditions under which orders are delivered while guaranteeing sustainable operations.

Thus, ensuring that the products are delivered in the shortest time possible between the placing of the order and its arrival at the consumer, the Order Fulfilment Centres network are the focus of optimisation, where sustainable operations are targeted.

Nespresso is a company that has a complex supply chain, given the several countries in the world in which it operates, the many products it commercialises and due to the shared responsibility with logistics operators, which are responsible for guaranteeing the arrival of an order to the Nespresso customer. Therefore, it has been decided that only a few countries distributed over a given area of the world coffee market will be analysed initially in this project, and these are representative of the highest volume of Nespresso demand. To help on this analysis, Nespresso's global supply chain centre contacted the OpLog Group from CEG-IST and based on this project collaboration the present Master Thesis has arisen.

This work is then to be developed exploring sustainable supply chain objectives: economic, environmental and social.

2.8. Nespresso – Current OFC Network Under Study

Currently Nespresso has a local OFC network, meaning that each OFC only supplies the country in which it is located and/or supplies a country which does not have an OFC. Thus, is important to understand which OFCs should be part of Nespresso distribution network, in the area under study, which markets they should supply and what impacts they have on the three levels of sustainability.

As mentioned above, this project will focus on only 19 countries which represent a significant volume for Nespresso. In most of these countries there is an OFC of the respective logistics operator, which is responsible for distributing the orders to the several customers of the country in which it is located. These OFCs store Nespresso products, but these OFCs are not for Nespresso's exclusive use, as they are owned by the logistical operators who deal with other companies. Countries without an OFC are supplied by an OFC in neighbouring countries.

In the case of two of the countries considered, as they have more than one OFC in the country, the demand is not 100% allocated to an OFC, but is divided by them according to the real demand. In the one country, there are 3 OFCs, two of which are allocated 30% of orders and the remaining 40% are allocated to the third OFC. In the other country, there are two OFCs, one covering 20% of orders, and the other OFC covering the remaining 80% of orders. In total 19 OFCs will be considered, as 3 of the countries included in this analysis do not have any OFC on their territory.

Taking all the above into account, the aim of this project is to define which of the current OFCs should be kept open, and the markets each provides, so that the Nespresso's supply chain is as sustainable as possible. No other OFC locations than the 19 OFCs are considered because the economic costs are too high and unrealistic for Nespresso's current objectives. The three pillars of sustainability will be considered, at the economic level the cost inherent in the supply chain will be optimised, at the environmental level the impacts caused by the transportation of orders and the capacity used for each OFC will be assessed, and finally at the social level the impact on the number of existing workers will be analysed, being this number will be weighted by the GDP and Unemployment Rate of each market/customer.

Given the growing trend of online shopping, and Nespresso's intention to promote that same growth, only current online sales demand as well as demand forecasts for the next 5 years will be taken into account. Due to confidentially reason the data used is a fictitious one although represents possible trends.

2.9. Chapter Conclusion

In this chapter the Nespresso company was introduced, highlighting its history and supply chain. The company's sustainability policies and strategies were also described, and its coffee capsules and the Nespresso collection and recycling process were characterised.

Subsequently, 3 companies were presented, with distinct characteristics, but which dominate or have great representativeness in the markets in which they are inserted. The supply chain of these companies was compared with Nespresso in order to establish similarities and differences in the companies present in this industry.

Finally, the main challenges of the capsule coffee market and Nespresso are described. The current part of the Nespresso supply chain under study was also presented in detail, and the objectives of this project were defined.

3. Literature Review

Given the challenges presented in the previous chapter, a literature review of the topics considered most important is described in this chapter.

This chapter is divided into four sections, the first of which describes the concept of supply chain and supply chain management. The second section then addresses the need for sustainability in a supply chain highlighting the types of decisions, the Triple Bottom Line (TBL or 3BL) Approach and the types of logistics within a supply chain are characterised. In the third section, Sustainable Supply Chain Design and Planning is described focusing on Forward Logistics Network Design. In addition, a set of models are presented in this section, which portray Forward Logistics or Closed Loop Supply Chain. Finally, a conclusion section is presented, in which the objective of this project is highlighted.

3.1. Supply Chain

Initially, the Supply Chain (SC) was defined simply as the sequential alignment of companies that provide products or services to the market (Lambert, Stock, & Ellram, 1998). However, over the years, the definition of the supply chain has changed with the integration of new entities.

The supply chain does not only include entities, organizational or individual, that are directly involved in the flow of products and services, but also includes all entities that are involved in the flow of finance and information. These types of flows are counted both upstream and downstream, i.e. from the primary source to the final consumer (Mentzer, Keebler, Nix, Smith, & Zacharia, 2001). As such, in addition to the suppliers of raw materials and the company responsible for manufacturing, it includes all entities such as: carriers, warehouses, retailers and consumers (Chopra & Meindl, 2013).

However, the supply chain is not limited to the forward flow. Consideration should also be given to all entities that are involved in the reverse flow, when, for example, there are product returns, rebates and recycling. Therefore, the forward and reverse flows, both at the level of physical product or service, information, finance and knowledge, should be considered (Ayers, 2001).

All supply chains have the same objective, which focuses on maximizing the value generated by it. This generated value is also known as supply chain surplus and can be obtained through the difference between what the product or service is worth to the consumer and the costs that come from its conception, for the entire supply chain (Chopra & Meindl, 2013). So, according to Londe & Masters (1994) the success of the supply chain is greater if the same objectives are shared in customer satisfaction.

3.1.1. Supply Chain Management

Many definitions of Supply Chain Management (SCM) have already been made, however this topic was only introduced in the literature by two consultants, R.K. Oliver and M.D. Weber in the early 1980s, who stated that supply chain management " is the process of planning, implementing, and controlling the operations of the supply chain with the purpose to satisfy customer requirements as efficiently as possible" (Mihai Felea & Irina Albăstroiu, 2013).

After this primary definition, several authors have been addressing and adding more characteristics and activities that define supply chain management. Stevens (1989) emphasizes that the objective of supply chain management is the balance between 3 very important factors for a company: the existence of a high service level, a low inventory level and a low unit cost (Mentzer et al., 2001). According to Cooper and Ellram (1993), to have an effective supply chain management it is necessary that both the risks associated with operations in the supply chain and the premiums from it must be shared (Mentzer et al., 2001). Tan, Kannan and Handfield state that in order to achieve a competitive advantage, supply chain management must focus on how it uses all of its processes and operations, technologies and capabilities, not forgetting the possibility of having a reverse flow (Mihai Felea & Irina Albăstroiu, 2013). Simchi-Levi, D., Kaminsky, P. and Simchi-Levi (2008) define SCM as a set of approaches that provide the production and distribution of the right quantity, at the right time and in the right place, achieving the satisfaction of consumers' requirements, but at the lowest cost (Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, 2008).

3.2. Sustainable Supply Chain

The concept of sustainability, according to the World Commission on Environment and Development (WCED), consists in meeting the needs of current generations without compromising the needs of future generations (Keeble, 1988). However, initially this concept was not fully understood by the companies, as they only added to the traditional financial bottom line, a thought about the environmental bottom line (John Elkington, 1999).

Currently, according to John Elkington in Cannibals With Forks: The Triple Bottom Line of 21st Century Business, it is considered a Sustainable Supply Chain (SSC) when it is aligned with the Triple Bottom Line Approach (John Elkington, 1999). This is the result of the interrelationship, interdependence and conflict between three dimensions: environmental, economic and social (Jeurissen, 2000). In the same sense Seuring & Müller (2008) define sustainable supply chain management "as the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customers and stakeholder requirements.".

By comparing a sustainable supply chain with one that is not considered as such, both aim to maintain competitive advantage through the permanent satisfaction of consumer needs and economic criteria set by all supply chain entities. However, these two types of chains are distinguished in the other two dimensions: environmental and social, since to be considered sustainable, the criteria defined in these two dimensions must also be met (Seuring & Müller, 2008).

Sometimes the same definition is given to the concept of Sustainable Supply Chain Management (SSCM) and the concept of Green Supply Chain Management (GSCM). However, these concepts are distinct. While Sustainable Supply Chain Management encompasses the 3 dimensions: economic, environmental and social, Green Supply Chain Management only refers to one dimension, the environmental. Thus, Green Supply Chain Management can be considered a part of Sustainable Supply Chain Management (Fritz, 2019).

A concept similar to the triple bottom line is corporate social responsibility (CSR), which corresponds to the idea that the company has a social and ethical responsibility towards stakeholders (employees, consumers, communities, investors supply chain members, among others) (Markley & Davis, 2007).

When building sustainable supply chains, in addition to integrating the three dimensions (economic, environmental and social) of the Triple Bottom Line Approach, it is very important to know what types of decisions (strategic, tactical and/or operational) are being addressed in establishing a sustainable supply chain, and which types of logistics (Forward Logistics, Reverse Logistic or Closed Loop Supply Chain) it is intended to incorporate into the supply chain. Thus, the intrinsic characteristics of these concepts are explained in detail in the next subsections.

3.2.1. Decision Levels

There are three types of supply chain decisions that are distinguished by their time horizon, i.e. they are differentiated by the time they will affect supply chains. Concerning a long-time horizon, the decisions are called strategic, whereas in the opposite way there are operational decisions that are characterized as short-term decisions. Between these two types of decisions, there are tactical decisions, with the time horizon being medium term.

The strategic decisions, as already mentioned, are long-term decisions and are related to decisions that involve the entire environment surrounding the company, leading to the creation of competitive advantage and market satisfaction (Allaoui, Guo, & Sarkis, 2019). The main decisions in the articles are related to the definition of network design, in which the analysis of transport and facilities location, the choice and integration of suppliers in the supply chain, risk assessment and the development of new products can be present (Allaoui et al., 2019; Barbosa-Póvoa, da Silva, & Carvalho, 2018).

Regarding tactical decisions, they are medium-term (Allaoui et al., 2019). Some examples of decisions addressed in articles are the planning and distribution of products and the inventory policies adopted by the company (Barbosa-Póvoa et al., 2018).

Finally, operational decisions are decisions taken daily, so their horizon is short term (Allaoui et al., 2019). The decisions in articles involve the scheduling of equipment and also human resources taking into account energy consumption and collaboration and evaluation of costs in CO_2 emissions (Barbosa-Póvoa et al., 2018).

3.2.2. Triple Bottom Line

The Triple Bottom Line approach (TBL or 3BL) allows companies to analyse and manage the equilibrium between the three dimensions designated above and understand how they intend to promote the interconnection between these three spheres in the future vision of the company (Jamali, 2006). This approach offers companies the prospect of activities that not only do not negatively affect the social and environmental dimensions, but can result in long-term economic gains and a greater competitive advantage (Carter & Rogers, 2008). However, the management of existing trade-offs between the different dimensions represents a challenge for companies (Jamali, 2006).

The economic dimension is the one in which companies feel most comfortable (John Elkington, 1999). This is justifiable because until the concept of sustainability in supply chains appeared, all business decisions were analysed according to revenue and costs. The main step is to understand what economic capital means. In a traditional approach, capital was only divided into physical capital, which includes the factory and all the machines the firm owns, and financial capital, which corresponds to the monetary value the firm owns. However, John Elkington (1999) also considers the existence of a third capital: intellectual capital, which consists of assets that are intangible, that is, unmeasured. In this dimension, it must be ensured “the long-term sustainability of a company’s costs, of the demand for its products or services, of its pricing and profit margins, of its innovation programs, and of its business ecosystem” (John Elkington, 1999).

Regarding the environmental dimension, the diffusion of the concept of sustainability at this level has dominated the society, and has changed the paradigm of the analysis of decisions in companies, sometimes choosing to change the designs of products and processes to contribute to their reuse or recycling (Kang, Kang, Shin, Kim, & Han, 2012). This pillar aims at identifying costs and revenues related to the environment, increased investment in environmental protection and the use of new indicators to assess environmental performance (John Elkington, 1999).

Concerning this dimension, several methods have been proposed to assess the impact of decisions on the environment, however, Life Cycle Assessment (LCA) is considered the most reliable. It considers all the life cycle of the product or service, quantifying the emissions and resources consumed from its production, the impacts on health and the environment, and also assesses the depletion of resources used (Mota, Gomes, Carvalho, & Barbosa-Povoa, 2015).

The third pillar of sustainability at the social level is sometimes somewhat neglected by companies, but it is a very important factor in determining the success of sustainability in the company (John Elkington, 1999). According to Pullman et al. (2009), social sustainability focuses on both internal communities, such as human resources, and external communities. This type of sustainability corresponds to offering equitable opportunities, promoting the link between the two communities mentioned above, encouraging diversity and ensuring quality of life (John Elkington, 1999).

The social dimension is considered the most difficult dimension to measure, which justifies the lack of articles evaluating it. Nevertheless, criteria based on the Sustainability Reporting Guidelines (SRG) have been used, which divides this dimension into four categories: Labour Practices and Decent Work, Human Rights, Society and Product Responsibility, and within each category there are several criteria. However, these criteria are considered subjective and qualitative, are mostly based on past events and do not focus on assessment at the strategic level but at the operational level (Mota, Gomes, Carvalho, & Barbosa-Povoa, 2015).

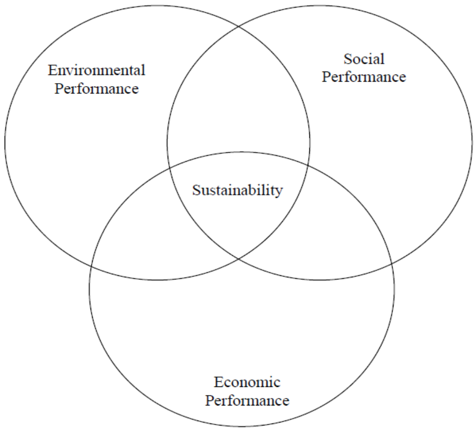


Figure 8: Sustainability: the triple, retrieved from Carter & Rogers, 2008

As can be seen in Figure 8, these three pillars described above are related, which means that one should not look at each one individually but at the relationship between them, since sustainability is only achieved when good performance in all three dimensions is achieved. According to Carter & Rogers (2008), when only sustainability is achieved, either economically and environmentally, or economically and socially, the result is positive. However, the same is not considered when sustainability is achieved at the environmental and social levels, since it considers this region as a question mark. The author considers this way, since it is not known beforehand at what cost these sustainability were achieved, and how this directly influences the existence of an organization (Carter & Rogers, 2008).

Different authors use different perspectives on sustainability in their articles and consequently different indicators to measure sustainability. Regarding the economic pillar, the most common indicator to assess sustainability is cost (59%), followed by profit (25%). In addition, in some articles, the net present value (NPV) and the risk associated with investment decisions are also used as sustainability measurement indicators (Barbosa-Póvoa et al., 2018). In the environmental pillar there is a wider distribution of the indicators used. There is a group of indicators, all related to carbon dioxide (CO2) emissions, which are used in more than 50% of the articles portraying the environmental pillar of the Triple Bottom Line Approach. In addition to these, waste reduction, recycling, Life Cycle Assessment (LCA) and the use of renewable energy are other indicators used in other articles (Barbosa-Póvoa et al., 2018). Finally, in the social pillar each author has only addressed one indicator in his approach to sustainability, and the diversity of indicators addressed reveals that the authors still do not have an accurate idea of the meaning of the social pillar in sustainability. Some of the indicators used are: job creation, working hours, discrimination, satisfaction and poverty (Barbosa-Póvoa et al., 2018).

There are several concepts that can be applied to companies in order to guide them in their quest for a Sustainable Supply Chain. However, because these concepts cover the three pillars of the Triple Bottom Line Approach differently, they provide different degrees of sustainability to the supply chain.

3.2.3. Supply Chain Logistics

For logistics within a supply chain there are two distinct types: Forward Logistics (FL) and Reverse Logistics (RL), which correspond to sets of opposite flows activities. While Forward Logistics encompasses all activities form the point of origin to the point of consumption, Reverse Logistics encompasses activities from the point of consumption to the point of origin. In addition to these logistics, it is also considered the Closed Loop Supply Chain (CLSC) which consists of the integration of Forward and Reverse Logistics.

To be able to assess the sustainability present in a supply chain, it is essential to know which supply logistics are being analysed, and thus in next subsections these three concepts will be analysed, highlighting their characteristics.

3.2.3.1. Forward Logistics

According to The Council of Logistics Management, Forward Logistics or simply Logistics represents a set of forward flow processes, which include planning, implementing and controlling flows efficiently, raw material costs, existing inventory, quantity of finished product and all related information (S. Rogers, Dale; S. Tibben-Lembke, 1998). So, it contains all the activities that are necessary for the product or service to move from the manufacturer to the consumer (Chen, Zhang, Shi, & Xia, 2019).

Some particularities such as the demand forecasting, the quality of the product and packaging and the definition of product transport routes five to the Forward Logistics characteristics that make it distinctive (Tibben-Lembke & Rogers, 2002).

Regarding demand forecast at Forward Logistics, it has a high degree of accuracy due to a better understanding of consumer needs resulting from communication between the various departments of the company (Tibben-Lembke & Rogers, 2002).

Another feature is the flow of products, which in general is carried out form one to many transports, i.e. from one or few points of origin, namely factories and warehouses, to many destinations' points, typified by consumers. The combination of this characteristic with the best forecast of demand leads to clearer and previously established routes (Tibben-Lembke & Rogers, 2002).

The growing need of consumers to get the products or services as soon as possible, leads to the development of all activities related to this logistics being carried out quickly, which can cause the immediate non perception of a customer's lack of satisfaction. This perception often occurs only when the customer's consumption is reduced or no consumption (Tibben-Lembke & Rogers, 2002).

Although the price of products is expected to be uniform, when entities such as retailers are present in the forward supply chain, consumers pay differently for the product, due to both the retailer from whom they buy and the quantity purchased (Tibben-Lembke & Rogers, 2002).

The quality of the product and packaging perceived by the consumer is uniform, since it is the responsibility of the company to control these processes in order to meet the requirements of the consumer (Tibben-Lembke & Rogers, 2002).

Concerning costs, Forward Logistics allows the company to have complete visibility both in terms of their value and nature, so these costs are usually divided into categories and are well defined and known (Tibben-Lembke & Rogers, 2002).

Due to all these aspects, this logistics provides the company with a look at the entire forward supply chain, allowing it to know exactly the origin of a certain product as well as the flows and entities through which that product has passed (Tibben-Lembke & Rogers, 2002).

3.2.3.2. Reverse Logistics

While Forward Logistics encompasses all activities from the point of origin to the point of consumption, Reverse Logistics includes the reverse flow activities, that is, from the point of consumption of the product to its point of origin (S. Rogers, Dale; S. Tibben-Lembke, 1998). Reverse Logistics has as main objectives the creation of value or the elimination of the product with the most appropriate process in view of its characteristics. In addition, it will also allow companies to recover value, which otherwise would not be recovered (Smith, 2005).

Regarding the dimensions of the Triple Bottom Line, according to Geisendorf & Pietrulla (2018), Reverse Logistics only encompasses economic and environmental sustainability, thus not considering the social level.

At the time of the article, Ferrer & Ayres (2000) described two major structural limitations that prevented RL from existing. The first relates to the infrastructure of most companies that was not suitable for reverse flow, and the second limitation refers to products that were not processed, i.e., did not undergo any kind of treatment, for their disposal or reuse, when they arrived at the companies after the reverse flow. However, due to the recognition of the potential in the recovery of products, of the legislation and guidelines created, and due to the growing awareness of the consumer and society (Ferrer & Ayres, 2000), the reverse flows and the benefits they bring to companies have been recognized, so the structures of supply chains have been changed to encompass the two types of flows, forward and reverse flows.

The existence of reverse flows in the supply chain allows products that have not been marketed to return to the company, redistribution of products for resale, recycling or re-use of products, and specialised treatment if the product is to be disposed of. In addition, since there are many products that constantly need support, this flow allows them to return to the company to be repaired, through the reverse flows, and then, after the repair, through the forward flows, return to the customer. Thus, the existence of RL is currently considered essential to the company's performance (Smith, 2005).

Besides all the features described above, RL also allows the company to identify common defects that occur and thus proceed to solve the problem at source. If the company did not have the perception that defects exist, it would never rectify them and its image could deteriorate (Smith, 2005). It also allows the reduction of inventory, transport and waste disposal costs, and can encourage customer loyalty, especially in the case of a network that allows product returns (Kannan, Murugesan, Senthil, & Haq, 2009).

Despite all these advantages and despite companies’ recognition that the existence of RL adds value to the company, it is often difficult to define the most appropriate network dimensions (Genchev, 2009). Consequently, in order to establish the most appropriate structure, there are some factors that must be taken into consideration. First, one must understand what kind of relationship the company has with the consumer, namely whether the product sold needs maintenance and whether it is included, whether there is purchase or just rental of a product or service, and other characteristics. In addition, given the existence of legislation to regulate the company's discards to the environment, it is necessary to understand whether this influences the customer, regarding the return of products. Another factor is related to the company's practice or not of incentives for the return of the products. Finally, it is necessary to understand whether the target market of the company is aware of the environmental impacts of a certain product and what influence its behaviour has on those impacts (Ayres, Ferrer, & Van Leynseele, 1997).

Concerning the activities present in the Reverse Logistics Network (RLN), depending on the author different activities are considered (Sangwan, 2017). While Fleischmann, Krikke, Dekker, & Flapper, 2000 only consider five activities: collection, inspection or separation, re-processing, re-distribution and disposal, Lambert et al (2011), identifies eight forms of product recovery: repair, reuse, remanufacture, upgrade, repackage, recycle, reconfigure, and revaluation, and Ferguson and Browne (2001) only identified reuse, remanufacture and recycle as ways to recover a product (Sangwan, 2017).

Comparing the characteristics between different Reverse Logistics, there are 5 main differences based on the degree of centralization; number of levels; links with other networks; open or closed loop structure and degree of branch co-operation. Centralized Reverse Logistics is considered if each activity is performed in a few locations. Regarding the number of levels, these indicate the vertical integration of each network. It can be considered a network of two types: single-level (all activities only take place in one facility) or multi-level (different activities carried out in different facilities). The third difference identified, relates to how Reverse Logistics is created, i.e. whether it is an independent structure of the previously existing network, or whether it is integrated into it. The fourth difference, the existence of an Open or Closed Loop, refers to the existence of only one direction, or the existence of two, in which sources and sinks coincide, respectively. The last difference indicates the existence or not of more entities in the creation of a Reverse Network (Fleischmann et al., 2000).

Analysing the described characteristics of Forward and Reverse Logistics, Fleischmann et al. (2000) identified the main differences arising from the use of each one. While in Forward Logistics, supply is considered an endogenous variable, in Reverse Logistics it is considered the opposite, i.e. an exogeneous variable, since in the first, the time, quantity and quality of the supplied products are controlled according to market needs, which is not true in Reverse Logistics. The consequence of this difference is that there is no Inspection/Separation activity in Forward Logistics (FL), because the target markets are known in advance and there is no differentiation of the destination depending on the quality of the product, which happens in Reverse Logistics. Another difference to highlight is the interaction between collection and re-distribution, in which transport can be combined in closed loop networks. Regarding the quantity of suppliers in the two types of Logistics, in the Reverse the number is much more substantial compared to the Forward, however, the relationship between volumes is reversed, with the existing filling stations supplying low volume, while in Forward Logistics the low number of suppliers represents a high volume.

3.2.3.3. Closed Loop Supply Chain

Initially, the Closed Loop Supply Chain (CLSC) was a term that only considered two dimensions: the economic and the environmental. However, it has been considered that an extension of this concept to include the social component should be made, despite the almost non-existence of models and/or frameworks that address both the environmental and social dimensions (Tang & Zhou, 2012).

Recalling that the CLSC incorporates both types of logistics, Forward and Reverse Logistics, it is possible to define Closed Loop Supply Chain Management (CLSCM) as “the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time” (Guide & Van Wassenhove, 2009).

It is recognised that the remanufacturing of a product is a "golden opportunity to deliver a sustainable future", since it makes it possible to reduce the energy consumed in the manufacture of all products and ensures specialised treatment of products at their end of life (Reimann, Xiong, & Zhou, 2019). However, remanufacturing is considered a more complex activity than traditional manufacturing since there is a high uncertainty regarding the amount of product that will be brought back to the point of origin, and due to the complexity of the process and coordination between the two flows (Chen et al., 2019). Therefore, in order to ensure all benefits, the product design needs to be changed to facilitate remanufacturing. This means that more investment is needed in the design of a new product, which will be balanced with a significant decrease in remanufacturing costs (Reimann et al., 2019).

For a network to be considered closed loop, it means that the flow of products, after they are recovered, returns to the same market, otherwise the network is considered open loop (Van Engeland, Beliën, De Boeck, & De Jaeger, 2020). Here is established one of the main differences for the circular economy, since it only aims at a constant recovery of materials, regardless of the target market.

With the definition of sustainability clearly present, it is possible to state that the existence of a CLSC does not guarantee a sustainable supply chain, as it is directly dependent on the involvement of the three dimensions that characterize sustainability.

3.3. Sustainable Supply Chain Design and Planning

The growing awareness of consumers and the growth of government policies are driving companies to change strategies and pursue optimised supply chain networks in order to become more sustainable, in all dimensions of the Triple Bottom Line Approach (economic, environmental and social). However, such goal where characterization of a supply chain that takes these three dimensions into account leads to the need of considering the existence of numerous relevant factors and consequently the existence of complex models (Mota, Gomes, Carvalho, & Barbosa-Póvoa, 2015). Given the case study, the models relating to Forward Logistics has a high importance and will be explored in the next section.

3.3.1. Forward Chain Models

Remembering that the case study consists in defining the Forward Supply Chain of Nespresso, considering the three dimensions of sustainability, will be analysed a set of models identified as more generic, which include forward logistics, and in which strategic and tactical decisions regarding the design and planning of a supply chain will be considered.

Table 1 presents the main characteristics of each model selected: the type of model performed by the authors, which network they characterize (Closed Loop Supply Chain or Forward Logistics), which dimensions of Sustainability are present in the model (Economic, Environmental and/or Social), which type of model they use (deterministic or stochastic), whether they have single or multiple objectives, the type of decisions they intend to make with the model (Strategic, Tactical or Operational) and finally, if so, to which type of industry the models were applied.

- Ramezani, Bashiri, & Tavakkoli-Moghaddam (2013) has developed a stochastic CLSC model, in which only the locations of suppliers and customers are known and fixed, and in which the location of the remaining facilities (plant, distribution centre, collection centre, hybrid processing facility and disposal centre) is desired to be established. In this model, the hybrid facility corresponds to a facility that works both forward and reverse. In addition to determining the locations already mentioned, it is intended to determine the existing flows between each entity restricted to its capacity limit and the existence of uncertainty parameters. In this model there are three objective functions that aim to maximize, respectively, total profit, responsiveness, and quality of the closed-loop network, being considered only the economic pillar of sustainability.
- Garg et al. (2015) present a model applied to a company that produces electrical appliances, in which an extension of the facilities will occur and faces the problem of managing transport activities. Deterministic parameters are used and the first objective of this model is to maximize the profit, however, it wants to do so by minimizing the company's carbon footprint. Therefore, the economic and environmental pillars are present in this model. The inherent decisions are strategic, due to the design of the CLSC Network, and tactics, related to transportation activities.
- Arampantzi & Minis (2017) has developed a model that is based on two methods in order to find an efficient solution regarding the three dimensions of sustainability. The two methods are the Goal Programming (GP) and ε-constraint. It is a model that includes only deterministic parameters and only considers Forward Logistics in the design and planning of the supply chain
- Mota et al., (2018) developed a model, at a strategic and tactical level, and applied it to a European based company with markets in Europe and South America. In this MOMILP model the performance of the three pillars of Sustainability was taken into account, with economic performance being evaluated with the Net Present Value (NPV) metric, environmental with the ReCiPe method and social with the Gross Domestic Product (GDP). Each of these pillars is represented in an objective function. Deterministic and stochastic parameters are used, the latter to introduce uncertainty of demand into the model.

Table 1: Main Characteristics of models selected

Article	**Model**	**Network Structure**		**Triple Bottom Line Dimension**			**Parameters**		**Objective**		**Decision**			**Application**
		FL	CLSC	Economic	Environmental	Social	Deterministic	Stochastic	Single	Multiple	Strategic	Tactical	Operational	
Ramezani, Bashiri, & Tavakkoli-Moghaddam (2013)	-		X	X				X		X	X			N.A.
Garg, Kannan, Diabat, & Jha (2015)	-		X	X	X		X			X	X	X		Electrical Appliances
Arampantzi & Minis, (2017)	GP	X		X	X	X	X			X	X	X		Manufacturer of commercial refrigerators
Mota, Gomes, Carvalho, & Barbosa-Povoa, (2018)	MOMILP		X	X	X	X	X	X		X	X	X		European Based Company
Zarbakhshnia, Soleimani, Goh, & Razavi (2019)	MILP		X	X	X		X			X	X	X		Home Appliance Company
Chen et al. (2019)	MINLP		X	X			X		X		X			N.A.

- Zarbakhshnia, Soleimani, Goh, & Razavi, (2019) presents a deterministic MILP model, that considers both forward and reverse logistics, where the number of supplier centres, manufacturing centres, warehouses and customers areas are known and fixed. On the other hand, it is intended to define the locations of distribution and collection centres, remanufacturing and revival centre, disposal centre and recycling centre. In order to establish the CLSC Network at a strategic and tactical level, two pillars are considered, the economic and the environmental.
- Chen et al. (2019) have developed a generic MINLP model for CLSC network design, that aims to know the location of Remanufactures, Distribution Centres and Collection Centres, being considered two types of market, online and offline. Only the economic pillar is present in this model, and in order to discover the maximum profit, deterministic parameters are used. Moreover, since only remanufactured products are considered, it is assumed that the inherent price of remanufactured products is lower than the production of a new product.

In the literature review performed, it was found that there is no model applied to the coffee companies and therefore more generic models have tended to be selected.

As can be seen in Table 1 only two of the selected models, from Mota et al., (2018) and from Arampantzi & Minis (2017) takes into consideration sustainability in its three dimensions. While Arampantzi & Minis (2017) model only considers logistics and deterministic parameters, the model developed by Mota et al., (2018) considers both deterministic and stochastic parameters, which provides the possibility of assessing the uncertainty associated to demand. Thus, model of Mota et al., (2018) will be chosen to be extended to the problem under study, elaborating an adaptation, since it only intends to consider the Forward Logistics.

3.4. Chapter Conclusions

In this chapter several concepts related to the supply chain structure and its sustainability were presented. In order to assess the sustainability present in a company, in addition to the Triple Bottom Line Approach, it is necessary to evaluate which types of decisions will be made and which logistics are present in the supply chain under study. In this way, all these concepts have been described, highlighting their main characteristics. Finally, models with different characteristics suitable to model the problem under study were identified and characterized, as presented in Table 1. One of the main problems encountered is that there is currently no specific or generalised model that has been applied to the coffee capsule collection network.

The objective of this project is to optimize Nespresso's distribution network, considering the three pillars of sustainability. As such, it is intended more specifically to try to reorganize the existing supply chain in order to understand where OFCs (Order Fulfilment Centres) must be located and which markets they must supply with the aim of making the supply chain more sustainable.

4. Model

4.1. Model Characterization

This chapter presents the main characteristics of the generic supply chain that is considered for the development of the optimisation model that will allow the design and planning of supply chain. It should be noted that this model covers only the forward supply chain and is based on the model in the work of Mota et al. (2018).

Three sets of entities are considered. The first corresponding to the factories is responsible for transforming the raw materials into the final product, the second corresponding to the OFCs (Orders Fulfilment Centres) and finally, the customers or markets that need to be satisfied. Figure 9 represents the generic supply chain network as well as the existing materials flows and the modes of transport that could be used. Entities and flows prior to the factory will not be considered.

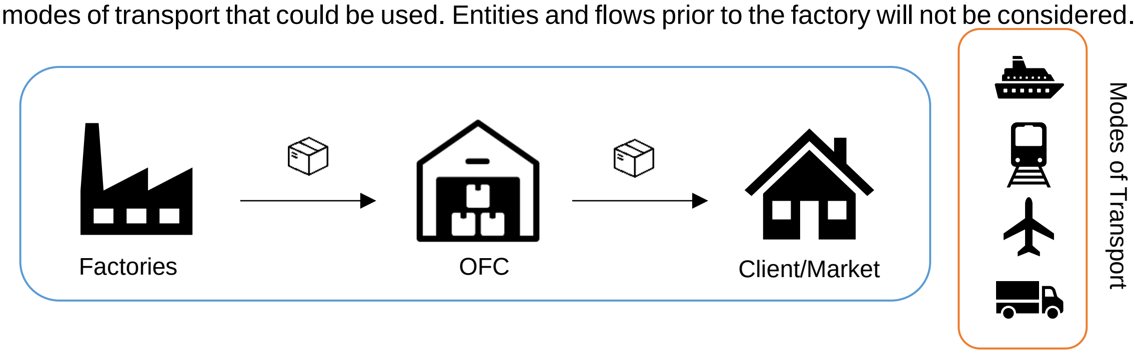


Figure 9: Representative scheme of the entities present in a generic supply chain

Through this structure of the network, it is intended to create a model that includes sustainability as a whole, based on existing entities, products and modes of transport, and that has as its objective the design of the supply chain considering the 3 dimensions of sustainability. Thus, at the economic level it is intended to minimize the total costs resulting from the network, at the environmental level it is intended to minimize the environmental impact caused by the transport of products between different entities, and finally, at the social level it is intended to maximize the social impact generated which will be evaluated according to two different indicators: GDP and Unemployment rate. In the environmental dimension will not assess the impact caused by the structures of the entities, firstly because this model does not considers the installation of entities but just it use, as factories are already installed and OFCs belong to logistics operators and not to the company that manufactures the products. In view of these objectives and considering the case study under study the aim is to define which OFCs should be used, which markets or customers they supply and what impacts are caused in each of the dimensions of sustainability.
Therefore, in order to elaborate and execute this model in view of the objectives and what is intended to be defined, the following data are required:

- Structure of potential or existing entities in the supply chain;
- Location of each entity;
- Set of products;
- Possible OFCs-Market allocation;

- Products allowed in each entity,
- Allowed modes of transport in each flow;
- Time horizon in study;
- Distance between entities;
- Fixed, Investment and Variable costs associated with the use of each OFC;
- Transport costs;
- Product demand by each customer in each period of time considered;
- Modes of transport used in each flow;
- Product weight;
- OFC capacities;
- Initial, maximum and minimal inventory levels;
- GDP and Unemployment Rate of each entity location;
- Environmental Impact of each transport mode.

4.2. Model Mathematical Formulation

In this section we will describe mathematically the whole model developed, and each sustainability dimension will be assessed separately. This was based on the work of Mota et al., (2018), however some adaptation had to be made regarding the case study analysed. Thus, the following points were considered:

- New economic objective function, which analyses the total costs existing in the network;
- Inclusion of a new cost type, which consequently leads to the inclusion of new variables, parameters and constraints;
- At the environmental level, only the environmental impact generated by the transport of products was considered;
- At the social level, a new way of determining the number of workers need in each entity, based on the average monthly productivity.

First, the sets will be defined, followed by the parameters to be used. Then, all variables needed for the sustainability analysis of the supply chain will be defined. Finally, the objective functions and restrictions are presented.

4.2.1. Sets

Consider I the set of locations or possible locations in which entities, such as factories, OFCs, and markets/clients are located. Thus, index i, io and id, represent specific entities corresponding to that set. In order to group according to the type of entities, different subsets were defined, being that I_f represents the set of possible or existing factories, I_w the set of possible locations of OFCs, I_c the set of markets or customers, I_{train} the set of train stations, I_{air} the set of airports and I_{port} the set of seaports. As such, $I_f \cup I_w \cup I_c \cup I_{train} \cup I_{air} \cup I_{port}$ are subsets that form the I set.

The *EntEnt* subset represents all possible flows between entities ($EntEnt = \{(i, io) : i \in I \wedge io \in I \wedge i \neq io\}$).

For the products considered, these are represented by the set *M* where *m* and *mm* constitute the index used to designate specific products.

Let *A* be the set of modes of transport possible to be used in this supply chain and be represented by index *a*. Subsets of modes of transport have been defined so that different characteristics of each mode of transport can be defined. Consequently, the following subsets have been defined: A_{truck} representing the trucks set, A_{air} the aircraft set, A_{train} the train set and A_{boat} the boat set. So, $A_{truck} \cup A_{air} \cup A_{train} \cup A_{boat}$ form the *A* set.

In order to define the possible links between products and entities, i.e., the possibility that a given entity contains a certain product, there is the subset *ProdE,* where $ProdE = \{(m, i) : m \in M \wedge i \in I\}$. *ProdF* represents the subset of possible product flows between entities such that $ProdF = \{(m, i, io) : (m, i) \in ProdE \wedge (i, io) \in EntEnt\}$. *Net* is a subset that establishes the mode of transport to be used in the connection between two entities ($Net = \{(a, i, io) : a \in A \wedge (i, io) \in EntEnt\}$). Finally, in order to establish the set of possible networks, there is the subset *NetP*, which provides the union of mode of transport, product and entities such that $NetP = \{(a, m, i, io) : (a, i, io) \in Net \wedge (m,i, io) \in ProdF\}$.

The time unit considered is the month, with *T* representing the set of all months considered and *t* the index of this set. To establish each category of environmental impact, there is the *Midpoint* set which is represented by *mp* index. Finally, in order to evaluate the uncertainty a stochastic approach is developed, and different possible scenarios are considered, the *SC* is considered the set of all scenarios that are represented by the *sc* index.

4.2.2. Parameters

The parameters used in the case study are separated into different categories:

- Entities:
    - $fixedcost_{I,t}$ – Fixed cost inherent to the use of the OFC *i* in time period *t*, $i \in I_w, t \in T$;
    - $handlingcost_{i,m}$– Cost of handling product m in OFC i, $i \in I_w$, m $\in M$;
    - $storagecost_{i,m}$ – Cost of storage product m in OFC i, $i \in I_w$, m $\in M$;
    - $pickingcost_{i,io,m}$ – Cost of preparation of the product m in OFC I for the client io, , $i \in I_w, io \in I_c$, m $\in M$;
    - $additionalfc_{io,id}$ - Cost that results from changing assets, and a increase in the capacity of the OFC;
    - $flowmax_i$ – Maximum number of orders in each entity, $i \in I$;
    - $hoursmax_i$ – Number of hours available in OFC for product preparation, $i \in I_w$;
    - $hourperorder_i$ – Number of hours required to prepare a customer order i, $i \in I_c$;

- *distance* $_{i,io}$ – Distance between two entities i e io, $(i, io) \in I$;
- *stockmax* $_{m,i}$ – Maximum product stock m in the entity i, $i \in (I_w \cup I_f), m \in M$;
- *stockmin* $_{m,i}$ – Minimum product stock m in the entity i, $i \in (I_w \cup I_f), m \in M$;
- *stocki* $_{m,i}$ – Stock of product m in entity i in the first period of time, $i \in (I_w \cup I_f)$, $m \in M$;

- Transport:
  - *captransp* $_a$ – Maximum contracted capacity of the mode of transport a, $a \in A$;
  - *pTranspCap* $_a$ – Capacity of the transport mode a, $a \in A$;
  - *vartransp* $_{a,i,io}$ – Cost of transport per product m and per km, between entities i and io, using the mode of transport a, , $(i, io) \in I,\ a \in A$;
  - *pCapmin* $_a$ – Minimum cargo to be transported using transport mode a, $a \in A$;

- Product:
  - *productweight* $_m$ – Weight of product m, $m \in M$;
  - *pBOMTsame* $_{m,mm}$ – Relation between products m entering and products mm leaving the OFC, train stations, airports and seaports , $(m, mm) \in M$;
  - *pBOMFsame* $_{m,mm}$ – Relation between products m entering and products mm leaving the factories , $(m, mm) \in M$
  - *demand* $_{m,i,t,sc}$ – Demand of client/market for product m in time period *t* according to the scenario *sc*, $i \in I_c , m \in M , t \in T,\ sc \in SC$.
- Social Parameters:
  - *Workerproductivity* $_m$- Amount of product m that a worker can prepare per month, $m \in M$;
  - *GDPInd* $_i$ – GDP per capita in PPS of entity i, $i \in I_w$;
  - *UnemploymentRateInd* $_i$ – Unemployment rate of the location of entity i, $i \in I_w$;
- Environmental Parameters:
  - *TranspImpact* $_{a,\ mp}$ – Characterization factor, by km and kg, of the environmental impact caused by the transport mode a in midpoint category mp, $mp \in Midpoint$, $a \in A$;
  - *NormFactor* $_{mp}$ – Normalization factor for each midpoint category, $mp \in Midpoint$;
- Other Parameters:
  - *probsc* $_{sc}$ – Probability of each scenario *sc* occurring, $sc \in SC$

4.2.3. Variables

In this model there are three types of variables: continuous variables that can only take positive values, binary variables that define whether a certain set or flow is active (value equal to 1) or not (value equal to zero), and auxiliary variables that help in the elaboration of the model and consequently in the definition of objectives. These variables are described below:

Continuous Variable

- $X_{m,a,io,id,t,sc}$ – Quantity of product *m* moved with the mode of transport *a* between the entities *io* and *id* in the period of time *t* according to the scenario $sc, m \in M, a \in A, (io, id) \in I,\ t \in T, sc \ \in \ SC$;
- $Production_{m,i,t,sc}$ – Quantity required to produce of product *m* in entity *i* in time period *t* according to the scenario *sc*, $i \in I_f , m \in M,\ t \in T, sc \ \in \ SC$;
- $S_{m,i,t,sc}$ **–** Quantity of product m that is in stock at entity *i* in time period *t* according to the scenario *sc*, $i \in \left(I_w \ \cup I_f \right), m \in M,\ t \in T, sc \ \in \ SC$;

Binary Variable

- Y_i = 1 if the entity i ∈ I is used, Y_i = 0 otherwise;
- $Z_{m,a,io,id,t,sc}$ = 1 if there is a flow of the product *m*, with the transport mode *a* between the entity *io* and *id*, in the time period *t* according to the scenario *sc,* , $m \in M, a \ \in A, (io, id) \in I,\ t \in T, sc \ \in \ SC$;

Auxiliary Variable

- *TC* – Total Cost of Supply Chain Network;
- $Workers_{io,id,t,sc}$ – Number of workers required per period of time *t,* to prepare the products in entity *io* to entity *id* according to the scenario *sc*¸ $t \in T$, $io \in \ I_w,\ id \ \in \ I_c\ ,\ sc \ \in \ SC$;
- $vworkers_{io,sc}$ - average number of workers needed in the entity io according to the scenario *sc*, $io \in \ I_w,\ \ sc \ \in \ SC$;
- *vGDPInd* – GDP indicator in the entire supply chain;
- *vUnemploymentRateInd* – Unemployment Rate Indicator in the entire supply chain;
- $vTranspImpact_{a,mp,sc}$ – Environmental impact of transport mode *a* in midpoint category *mp* according to the scenario *sc*, $a \in A , mp \in Midpoint,\ \ sc \ \in \ SC$;
- *vEnvImpact* – Total environmental impact.

4.2.4. Objective Functions

Considering the previous subsections, in which the sets, parameters and variables were defined, this subsection will define the three objective functions considered for the assessment of the sustainability in the supply chain.

4.2.4.1. Economic Objective Function

$$
\begin{aligned}
Min\ TC = \sum_{sc \in SC} probsc_{sc} \sum_{t \in T} \Bigg(& \sum_{i \in I_w} fixedcost_{i,t} * y_i + \sum_{(m,i) \in ProdEnt} stockcost_{i,m} \times S_{m,i,t,sc} \\
& + \sum_{(a,m,io,id) \in NetP} pickingcost_{io,id,m} \times X_{m,a,io,id,t,sc} \\
& + \sum_{(a,m,io,id) \in NetP} handlingcost_{io,m} \times X_{m,a,io,id,t,sc} \\
& + \sum_{(a,m,io,id) \in NetP} additionalfc_{io,id} \times Z_{m,a,io,id,t,sc} \\
& + \sum_{(a,m,io,id) \in NetP} vartransp_{io,id} \times X_{m,a,io,id,t,sc} \times distance_{io,id} \Bigg)
\end{aligned}
\tag{4.1}
$$

As already mentioned, the aim of the objective function of the economic dimension (equation (4.1)) is to minimize the total costs (TC) in the forward supply chain. For that purpose, 6 types of costs are considered. The first cost results from the opening OFCs and is given by the product of the fixed cost ($fixedcost_{i,t}$) by the variable indicating whether that OFC is open or not (y_i). The second cost type is the storage cost, which correspond to the unit cost of the product *m* being in stock in entity *i* ($stockcost_{i,m}$) multiplied by the number of products ($S_{m,i,t,sc}$) in a given time interval.

The third and fourth types of cost correspond respectively to the total picking and handling cost of the products, where in the first, the flow ($X_{m,a,io,id,t,sc}$) is multiplied by the unit price of preparing of the product ($pickingcost_{io,id,m}$), depending on the OFC where this preparation is made and on the market where it will be delivered, while in the latter it is multiplied by the unit cost of handling the product while it is in the OFC *io* ($handlingcost_{io,m}$).

The fifth cost type is the additional fixed cost, which results from the change of OFC that satisfies a given market, when compared with the current network. In other words, the allocation of orders between OFCs imply a related to the capacity to store and prepare orders that has to be higher. Therefore, this cost is given by the additional cost ($additionalfc_{io,id}$) multiplied by the binary variable that indicates if there is a flow of the product m between these two entities ($Z_{m,a,io,id,sc}$).

Finally, the last term is the variable transhipment cost that corresponds to the transportation costs of the products between two entities, which results from multiplying the variable transport cost per Km and per Kg ($vartransp_{io,id}$) between the *io* and *id* entities by the flow of product *m* between these entities ($X_{m,a,io,id,t,sc}$) and the distance between them ($distance_{io,id}$).

In addition, this objective function takes into account the probability of occurrence of each scenario *sc* ($probsc_{sc}$).

4.2.4.2. Environmental Objective Function

$$Min\ vEnvImpact = \sum_{sc \in SC} probsc_{sc} \times \sum_{\substack{a \in A \\ mp \in Midpoint}} NormFactor_{mp} \times vTranspImpact_{a,mp,sc} \tag{4.2}$$

The equation (4.2) corresponds to the objective function according the environmental dimension and it aims to minimize the environmental impacts caused by the transport of products. Consequently, the environmental impact generated by the network corresponds to the sum of the environmental impacts of the transport mode *a* in the *mp* impact category ($vTranspImpact_{a,mp,sc}$), weighted by the normalization factor of the *mp* category ($NormFactor_{mp}$), used to obtain a single score and considering the probability of each scenario considered.

4.2.4.3. Social Objective Function

$$Max\ vGDPInd = \sum_{sc \in SC} probsc_{sc} \times \sum_{i \in I_w} \frac{1}{GDPInd_i} \times vworkers_{i,sc} \tag{4.3}$$

$$Max\ vUnemploymenyRateInd = \sum_{sc \in SC} probsc_{sc} \times \sum_{i \in I_w} UnemploymentRateInd_i \times vworkers_{i,sc} \tag{4.4}$$

In the social dimension, as mentioned above, there are two objective functions, being that equation (4.3) corresponds to the maximization of the GDP indicator, which means, to use the OFCs and potentiate the products' volume in them, in locations where the GDP is lower. To this end, the number of workers needed in each entity ($vworkers_{,sci}$) is multiplied by the inverse of the $GDPInd_i$ parameter (Mota et al., 2018). According to Unemployment Rate Indicator (equation (4.4), it aims to use the OFCs and potentiate the products' volume in them, in locations where the Unemployment Rate is higher, and then, calculated by the product of the unemployment rate of the location of entity *i* ($UnemploymentRateInd_i$) by the number of workers needed in each entity ($vworkers_{i,sc}$). In both equations the probability of occurrence of each scenario is also taken into consideration.

4.2.5. Constraints Formulation

Based on the characteristics of the problem presented and considering the sets, parameters and variables mentioned, it is presented below the constraints that characterize a generic problem that aims to define the OFCs network that should be used in supply chain composition.

4.2.5.1. Demand Constraint

$$\sum_{\substack{io:(m,io,id)\in ProdF_{INCFP} \\ a:(a,m,io,id)\in NetP}} X_{m,a,io,id,t,sc} = demand_{id,m,t,sc}, m \in M \wedge id \in I_c \wedge t \in T \wedge sc \in SC \quad (4.5)$$

In most companies that commercialize products, one of the main goals is the total satisfaction of all markets/clients. As such, the equation (4.5) refers to demand, in which it is guaranteed that, in each period of time, the quantity of each product that reaches the market is equal to the demand of that customer. This ensures that 100% of demand is met. In case it is only aimed that a percentage of markets/costumers are fully satisfied, a parameter could be added to the second member of the equation that defines exactly this approach.

4.2.5.2. Material Balance Constraints

$$production_{m,i,t,sc} + S_{m,i,t-1,sc} = \sum_{\substack{mm,id:\,(mm,i,id)\in ProdF_{OUTFFP} \\ a:\,(a,mm,i,id)\in NetP}} pBOMFsame_{m,mm} * X_{m,a,i,id,t,sc} + S_{m,i,t,sc}, \quad (4.6)$$
$$m \in M \wedge i \in I_f \wedge t \in T \wedge sc \in SC$$

$$\sum_{\substack{mm,io:(mm,io,i)\in ProdF_{INWFP} \\ a:(a,mm,io,i)\in NetP}} pBOMTsame_{m,mm} \times X_{mm,a,io,i,t,sc} + S_{m,i,t-1,sc} = \sum_{\substack{mm,id:(mm,i,id)\in ProdF_{OUTWFP} \\ a:(a,mm,i,id)\in NetP}} pBOMTsame_{m,mm} \times X_{m,a,i,id,t,sc} + S_{m,i,t,sc}, m \in M \wedge i \in I_w \wedge t \in T \wedge sc \in SC \quad (4.7)$$

$$\sum_{\substack{mm,io:(mm,io,i)\in ProdF_{INTRAIN} \\ a:(a,mm,io,i)\in NetP}} X_{mm,a,io,i,t,sc} \times pBOMTsame_{m,mm} = \sum_{\substack{mm,io:(mm,i,id)\in ProdF_{OUTTRAIN} \\ a:(a,mm,i,id)\in NetP}} X_{mm,a,i,id,t,sc} \times pBOMTsame_{m,mm}, \quad (4.8)$$
$$m \in M \wedge i \in I_{train} \wedge t \in T \wedge sc \in SC$$

$$\sum_{\substack{mm,io:(mm,io,i)\in ProdF_{INAIR} \\ a:(a,mm,io,i)\in NetP}} X_{mm,a,io,i,t,sc} \times pBOMTsame_{m,mm} = \sum_{\substack{mm,io:(mm,i,id)\in ProdF_{OUTAIR} \\ a:(a,mm,i,id)\in NetP}} X_{mm,a,i,id,t,sc} \times pBOMTsame_{m,mm}, \quad (4.9)$$
$$m \in M \wedge i \in I_{air} \wedge t \in T \wedge sc \in SC$$

$$\sum_{\substack{mm,io:(mm,io,i)\in ProdF_{INPORT}\\ a:(a,mm,io,i)\in NetP}} X_{mm,a,io,i,t,sc} \times pBOMTsame_{m,mm} = \sum_{\substack{mm,io:(mm,i,id)\in ProdF_{OUTPORT}\\ a:(a,mm,i,id)\in NetP}} X_{mm,a,i,id,t,sc} \times pBOMTsame_{m,mm}\,, \quad m \in M \wedge i \in I_{port} \wedge t \in T \wedge sc \in SC \qquad (4.10)$$

The five equations present in the material balance refer to the balance in three different entities: factories, OFCs, train stations, airports and seaports.

Equations (4.6) and (4.7) correspond to the material balances at the factories and OFCs respectively. In the first, in each period of time, in each factory and for each product, it is ensured that the production ($production_{m,i,t,sc}$) added to the previous period's existing stock ($S_{m,i,t-1,sc}$) is equal to the quantity that leaves the factory ($X_{m,a,i,id,t,sc}$) added to the remaining stock in that period of time ($S_{m,i,t,sc}$). However, in the first period of time considered, the previous stock ($S_{m,i,t-1}$), is replaced by the parameter *stocki* $_{m,i}$,which corresponds to the initial stock of product m, in factory *i*.

Regarding the material balance at OFCs (equation (4.7)), as in the case of factories, for each product, each OFC and for each period of time, the flows entering in the OFC ($X_{mm,a,io,i,t,sc}$), considering the bill of materials ($pBOMTsame_{m,mm}$), plus the existing stock in the previous period of time ($S_{m,i,t-1,sc}$), have to be equal to the flows leaving the OFC for the markets ($X_{m,a,i,id,t,sc}$) , multiplied by the bill of materials ($pBOMTsame_{m,mm}$), plus the remaining stock in the OFC ($S_{m,i,,t,sc}$). For *t=1* the variable $S_{m,i,t-1,sc}$ has to be replaced by the parameter *stocki* $_{m,i}$.

The last three equations of this group (equations (4.8), (4.9) and (4.10)) correspond to the cross docking in train stations, airports and seaports respectively, where no products in stock are allowed. Therefore, these equations aim to define that everything that enters in these entities must leave, for each product and for each time period according to each scenario considered.

4.2.5.3. Maximum Flow Constraints

$$\sum_{a,m,io:(a,m,io,i)\in NetP} X_{m,a,io,i,t,sc} \leq flowmax_i * y_i\,, i \in I_w \wedge t \in T \wedge sc \in SC \qquad (4.11)$$

$$\sum_{a,m,i:(a,m,io,i)\in NetP} X_{m,a,io,i,t,sc} \leq flowmax_{io} * y_{i0}\,, io \in I_w \wedge t \in T \wedge sc \in SC \qquad (4.12)$$

$$\sum_{\substack{a,m,i:(a,m,io,i)\in NetP\\ i\in I_c}} X_{m,a,io,i,t,sc} \times hourperorder_i \leq horamax_{io} * y_{i0}\,, io \in I_w \wedge t \in T \wedge sc \in SC \qquad (4.13)$$

Equations (4.11), (4.12) and (4.13) restrict the flow between each pair of entities, if they are open. However, this limitation in the flow can be evaluated in two different parameters, one referring to the maximum order quantity (equations (4.11) and (4.12)), and the other referring to the number of hours available in the OFC for the products preparation (equation (4.13)). Therefore, equations (4.11) and (4.12) ensure that neither incoming nor outgoing flows, respectively, exceed the maximum flow allowed in each OFC ($flowmax_i$), in each period of time and scenario, if it is open (y_{i0}). On the other hand, equation (4.13) ensures that, for each OFC and for each period of time and scenario, the total number of hours spent in products preparation for the respective market has to be lower than the maximum hours available in that OFC ($horamax_{io}$), if it is open (y_{i0}).

4.2.5.4. Product Stock Limitation Constraints

$$S_{m,i,t,sc} \leq stockmax_i * y_i \text{ , } i \in I_w \wedge m \in M \wedge t \in T \wedge sc \in SC \tag{4.14}$$

$$S_{m,i,t,sc} \geq stockmin_i * y_{i,} \ i \in I_w \wedge m \in M \wedge t \in T \wedge sc \in SC \tag{4.15}$$

Equations (4.14) and (4.15) ensure that for each period of time, scenario, product, and for each OFC if it is opened, the existing stock ($S_{m,i,t}$) either cannot be greater than the maximum allowed stock ($stockmax_i$) or cannot be lower than the minimum allowed stock ($stockmin_i$).

4.1.1.1. Transport of Products

$$\sum_{m:(a,m,io,id) \in NetP} X_{m,a,io,id,t,sc} \leq captransp_a \text{ , } \quad (a,io,id) \in Net \wedge t \in T \wedge sc \in SC \tag{4.16}$$

$$\sum_{\substack{a,io:(a,m,io,i) \in NetP \\ io \in I \setminus I_{train}}} X_{mm,a,io,i,t,sc} = \sum_{\substack{a,id:(a,m,i,id) \in NetP \\ id \in I_{train}}} X_{mm,a,i,id,t,sc} \text{ , } m \in M \wedge i \in I_{train} \wedge t \in T \wedge sc \in SC \tag{4.17}$$

$$\sum_{\substack{a,io:(a,m,io,i) \in NetP \\ io \in I \setminus I_{air}}} X_{mm,a,io,i,t,sc} = \sum_{\substack{a,id:(a,m,i,id) \in NetP \\ id \in I_{air}}} X_{mm,a,i,id,t,sc} \text{ , } m \in M \wedge i \in I_{air} \wedge t \in T \wedge sc \in SC \tag{4.18}$$

$$\sum_{\substack{a,io:(a,m,io,i) \in NetP \\ io \in I \setminus I_{port}}} X_{mm,a,io,i,t,sc} = \sum_{\substack{a,id:(a,m,i,id) \in NetP \\ id \in I_{port}}} X_{mm,a,i,id,t,sc} \text{ , } m \in M \wedge i \in I_{port} \wedge t \in T \wedge sc \in SC \tag{4.19}$$

For the products transportation, equation (4.16) ensures that the total flow between a pair of entities, in each time period and in each scenario, cannot exceed the contracted transport capacity ($captransp_a$).

Equations (4.17), (4.18) and (4.19) stipulate that, for each time period and scenario, for each product entering a train station, airport or seaport respectively, it must be transported by the respective transport mode for another train station, airport or seaport.

4.1.1.2. Flow Existence Constraints

$$Z_{m,a,io,id,t,sc} \times BigM \geq X_{m,a,io,id,t,sc}\ , (a,m,io,id) \in NetP \wedge t \in T \wedge sc \in SC \qquad (4.20)$$

$$\sum_{io \in I} Z_{m,a,io,id,t,sc} = 1\ , (a,m,io,id,sc) \in NetP \wedge id \in I_c \wedge t \in T \wedge sc \in SC \qquad (4.21)$$

Equation (4.20) states that if variable $X_{m,a,io,id,t,sc}$ is positive, then the variable $Z_{m,a,io,id,t,sc}$ has to take value equal to 1. Equation (4.21) establishes that each market can only be satisfied by one OFC.

4.1.1.3. Social Indicator Constraints

$$workers_{io,id,t,sc} = \sum_{m \in M} \sum_{a \in A} \frac{X_{m,a,io,id,t,sc}}{workerproductivity_m}\ , io \in I_w \wedge id \in I_c \wedge t \in T \wedge sc \in SC \qquad (4.22)$$

$$workers_{io,sc} = \sum_{id \in I} \sum_{t \in T} \frac{workers_{io,id,t,sc}}{12}\ , io \in I_w \wedge sc \in SC \qquad (4.23)$$

In terms specific to the social dimension there are two additional equations (equations (4.22) and (4.23)). The first is used to calculate the number of workers needed ($workers_{io,id,t,sc}$), in each period of time and scenario, to prepare the products that will be shipped from OFC *io* to each market id, based on the average productivity in each product ($workerproductivity_m$). Equation (4.23) aims to calculate the average monthly number of workers required in OFC *io* ($workers_{io,sc}$) considering the markets *id* it supplies.

4.1.1.4. Environmental Indicator

$$vTranspImpact_{a,mp,sc} = \sum_{m,io,id:(a,m,io,id) \in NetP} \sum_{t \in T} TranspImpact_{a,mp} \times Productweight_m \times Distance_{io,id} \times X_{m,a,io,id,t,sc}\ , a \in A \wedge mp \in Midpoint \wedge sc \in SC \qquad (4.24)$$

For the environmental dimension, equation (4.24) defines the total impact caused by the mode of transport *a* at each midpoint *mp* and in each scenario considered ($vTranspImpact_{a,mp,sc}$). Therefore, this impact corresponds to the impact by mode of transport and by category of impact considered per Kg transported and per Km travelled ($TranspImpact_{a,mp}$), multiplied by the weight of the product ($Productweight_m$), distance travelled between two entities ($Distance_{io,id}$), and the total quantity transported ($X_{m,a,io,id,t,sc}$).

4.2. Chapter Conclusions

A generic model for supply chain planning and design has been described in this chapter, in which only the direct logistics is included, being the main objective to be able to locate the OFCs in order to generate less impact on the sustainability of the supply chain.

Given the desire to assess the sustainability of the supply chain, in addition to the presentation of sets, parameters and variables, the objective functions are presented according to each dimension of sustainability: economic, environmental and social, followed by the constraints. The resulted model is a MILP (Mixed Integer Linear Programming) model.

It is important to note that in the present model only demand is considered as a possible parameter subject to uncertainty, and therefore it is possible to define different values according to the scenario considered. Nevertheless, other parameters may take different values, so they may also depend on the scenario, and the model should be adjusted to make these new considerations.

Regarding the objective functions, four were developed, and it should be noted that in those concerning the social dimension, two indicators have been considered, but others can be used, as well as different costs can be associated to a supply chain.

5. Case Study: Data Collection and Treatment

In this chapter, the model previously presented will be applied to the Nespresso case-study described in chapter 2. It will also highlight all the assumptions made and how data was handled in order to obtain some parameters. As stated before the data presented is fictitious although does not compromises the characteristics of the network under study.

5.1. Assumption and Simplifications

In order to reduce the complexity and extent of the data, it was necessary to adopt strategies, which would make possible to implement the model without having a significant impact on the results obtained.

Firstly, despite the existence of a wide range of products commercialized by Nespresso, and the possibility of categorizing these products, taking into consideration that there are a undifferentiation of products in the cost practiced by the logistics operators, in this case study is only considered one type of product, named by order. The order is considered as an aggregation of capsules. Such assumption is justified as we are dealing with a strategic problem and such aggregation translates on average the products of Nespresso, as discussed with the company.

Regarding the number of years analysed, in this case study a time horizon of 5 years was considered. This time horizon is justified by the inexistence of investment by Nespresso in its own OFCs and the consequent contractualisation of OFCs to logistics operators. These 5 years will be divided on a monthly scale.

5.2. Data Collection and Treatment

In order to implement the model in the case study several data were collected as well as their treatment was performed so that the future analysis of the results would be simplified.

Therefore, data were collected regarding the characterization of the network, which included the geographic area covered by the case study, defining the most appropriate location of each market taking into account the geographical distribution of demand in each one, the possible links between OFCs and markets, followed by economic, environmental and social data.

5.2.1. Network Characterization

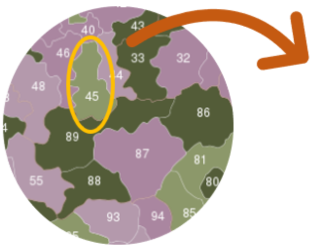
Although Nespresso is a company that is present in several markets worldwide, in terms of geographical area covered, only 19 countries with the highest volume of demand will be included in this study.

Due to the high number of customers in the countries considered, and the need for a model to be computationally feasible, an aggregation at customer entity level has been performed, which aims to not compromise case study main characteristics when considering them in the model. So, each country covered in this study is equivalent to a market or customer. This aggregation is a result of transport costs given by logistics operators to Nespresso, which depend only on the country in which they are delivered and not on a specific location. Table 2 shows all the entities considered in this case study:

Table 2: Nespresso's Entities

OFC	Market	Train Station
OFC1	MarketA	train1
OFC2	MarketB	train2
OFC3	MarketC	train3
OFC4	MarketD	-
OFC5	MarketE	-
OFC6	MarketF	-
OFC7	MarketG	-
OFC8	MarketH	-
OFC9	MarketI	-
OFC10	MarketJ	-
OFC11	MarketK	-
OFC12	MarketL	-
OFC13	MarketM	
OFC14	MarketN	-
OFC15	MarketO	-
OFC16	MarketP	-
OFC17	MarketQ	
OFC18	MarketR	-
OFC19	MarketS	-

Taking into account the previous assumption and due to the area covered by each country, and in order not to consider an arbitrary distance between two entities, data processing regarding the location and demand of all customers was performed, resulting in a geographical coordination of each country weighted by demand.



Postal Code 45	Orders
4501	879
4502	775
...	...
4595	319
4596	262
Total	21539

Average Postal Code: 4556
Orders: 2.18%
Latitude: 47.972451
Longitude: 14.166310

Figure 10:Representative scheme of the average postal code definition.

In a more detailed way, each country was divided into several groups, represented by the first two digits of the postal code. Once these groups were defined, the average postal code of each group was calculated considering the demand of each postal code of the group (Figure 10). In making this consideration, it was assumed that the postal code XX02 is located next to the postal code XX01, and so on for the remaining codes. Once the average postal code of the group had been defined, it was checked which were the coordinates of each, or the coordinates of a postal code close numerically if the average postal code did not exist. With the coordinates of each group and the representativity, in percentage, of that group in the total orders of the country, it was possible to define the coordinates of each country. In order to develop this process, it was necessary to verify the veracity of the postal codes, i.e. whether a certain group of postal codes exists or whether there were any errors in typing the codes in the data provided by Nespresso.

In terms of flows between entities, there is no limitation as regards the link between the factory and OFCs but flows between OFCs and markets are limited. The existence of this link between the entities is determined by the capacity to deliver orders within the stipulated period and by the cut-offs at both customers and OFCs.

In most of the markets covered in this study, orders are delivered to the customer no later than 24 hours after they place the order. Cut-offs refer to both markets and OFCs. For markets, the cut-off corresponds to the hours until which customer can place his order, to be delivered the next day. On the OFC side, the cut-off corresponds to the hours until which the OFC prepares the orders to be delivered the next day. Each market and each OFC have their own agreed cut-off times, so for a given OFC to supply a market, the difference between the cut-off times must be enough so that the OFC can prepare all orders to be delivered the next day. Thus, if these two factors are not combined, i.e. the OFC cannot prepare all the orders and they are not delivered within the stipulated time interval in each market, it is not possible to link this pair of entities. Thus, the allowed OFCs-Market allocations are defined in Table 3.

Table 3: Possible OFCs-Market allocations

OFC	***Possible Connection Markets***				
OFC1	MarketS	MarketQ	MarketK	MarketE	MarketB
OFC2	MarketR	MarketM	MarketI	MarketC	-
OFC3	MarketS	MarketQ	MarketM	MarketE	MarketB
OFC4	MarketP	MarketO	-	-	-
OFC5	MarketN	-	-	-	-
OFC6	MarketN	-	-	-	-
OFC7	MarketN	-	-	-	-
OFC8	MarketM	-	-	-	-
OFC9	MarketL	-	-	-	-
OFC10	MarketS	MarketQ	MarketK	MarketE	MarketB
OFC11	MarketJ	-	-	-	-
OFC12	MarketJ	-	-	-	-
OFC13	MarketP	MarketH	MarketD	-	-
OFC14	MarketG	-	-	-	-
OFC15	MarketF	-	-	-	-
OFC16	MarketE	-	-	-	-
OFC17	MarketP	MarketO	MarketH	MarketD	-
OFC18	MarketR	MarketI	MarketC	-	-
OFC19	MarketN	MarketJ	MarketA	-	-

Based on the geographical area, it was possible to define which transportation modes will be used for the orders distribution. Air transport has been removed from the possibilities due to the higher costs and not having to cross an ocean to satisfy a given market. So, only the land modes of transport became available and 3 types will be used: train, commercial truck, cargo truck.

The first mode of transport is only used to transport orders from the factory to the OFC1 and OFC17. For the remaining flows to the OFCs the cargo truck is used. For the orders distribution from the OFCs to the different markets is used the commercial truck.

The use of the train as a mode of transport implies an intermodal transportation, i.e., the cargo truck is used for orders arriving at the train station and from the stations to the OFC.

5.2.2. Forecast Demand

Based on the real demand in 2019, it is possible to forecast, the future demand in terms of number of annual orders, for the years 2020 to 2023. However, to obtain this demand it is required to define two types of growth/decrease rate. On the one hand, there is the growth/decrease rate in demand for the number of capsules per order and on the other hand, the growth/decrease rate in demand for the number of capsules per year.

As referred above, on average, in the countries considered in this case study, one order is equivalent to a set of capsules. However, this set constitution is different for each market. In addition, it is considered hypothetically that this value will decrease by 3% annually in all markets, and this 3% corresponds to the capsule growth rate per order (CGRPO) (Table 24 in Appendix 1).

In terms of the number of capsules per year, which is equivalent to the capsule annual growth rate (CAGR), the value is distinct for each country covered, ranging from -6.8% for the MarketH to +21.5% for the MarketB (Table 24 in Appendix 1).

The mathematical combination of these values will thus make it possible to determine the demand, in terms of the number of orders, for each country/market. Firstly, the number of capsules per order in each market in the year t+1, is given as a function of the annual growth rate in the number of capsules per order (CGRPO) and the number of capsules per registered/planned order in the previous year (equation(5.1)). The annual demand for capsules in year t+1 for each market is derived both from the associated growth rate (CAGR) and from the previous year's value (equation(5.2)).

$$Capsules\ per\ order_{t+1} = Capsules\ per\ order_t * (1 + CGRPO) \quad (5.1)$$

$$Annual\ Capsules_{t+1} = Annual\ Capsules_t * (1 + CAGR) \quad (5.2)$$

In order to obtain the number of annual orders for each market, since this is the relevant unit for certain parameters, including demand and costs, the equation (5.3) is used.

$$Annual\ Orders_t = \frac{Annual\ Capsules_t}{Capsules\ per\ order_t} \tag{5.3}$$

The annual demand growth (ADG) in the number of orders in each market will be given by equation (5.4)

$$ADG = \frac{Annual\ Orders_{t+1} - Annual\ Orders_t}{Annual\ Orders_t} \tag{5.4}$$

The following equations represent the development of equation (5.4) using the definitions of annual orders (equation (5.3)), the number of annual capsules (equation (5.2)) and the number of capsules per order (equation (5.1)).

$$ADG = \frac{\frac{Annual\ Capsules_{t+1}}{Capsules\ per\ order_{t+1}} - \frac{Annual\ Capsules_t}{Capsules\ per\ order_t}}{\frac{Annual\ Capsules_t}{Capsules\ per\ order_t}} \tag{5.5}$$

$$ADG = \frac{\frac{Annual\ Capsules_t * (1 + CAGR)}{Capsules\ per\ order_t * (1 + CGRPO)} - \frac{Annual\ Capsules_t}{Capsules\ per\ order_t}}{\frac{Annual\ Capsules_t}{Capsules\ per\ order_t}} \tag{5.6}$$

$$ADG = \frac{\frac{Annual\ Capsules_t * (1 + CAGR) - Annual\ Capsules_t * (1 + CGRPO)}{Capsules\ per\ order_t * (1 + CGRPO)}}{\frac{Annual\ Capsules_t}{Capsules\ per\ order_t}} \tag{5.7}$$

$$ADG = \frac{\frac{Annual\ Capsules_t * (CAGR + CGRPO)}{Capsules\ per\ order_t * (1 + CGRPO)}}{\frac{Annual\ Capsules_t}{Capsules\ per\ order_t}} \tag{5.8}$$

By simplifying equation(5.8), it is obtained the equation (5.9), which corresponds to the annual demand growth (ADG) for each market can be given by, where CAGR represents the capsule annual growth rate, and CGRPO the capsule growth rate per order.

$$ADG = \frac{CAGR - CGRPO}{1 + CGRPO} \tag{5.9}$$

Hypothetically considering the CGRPO equal to 3% in all markets, and the CAGR equal to -4.1% for MarketP and equal to 21.5% for MarketB, for the MarketP, ADG is equal to -1.14%, meaning that there is a decrease in the number of annual orders in that market, and for the MarketB, ADG is equal to 25.29% meaning a significant increase in the number of orders per year in that market.

In addition to the MarketP, also the MarketN, MarketM, MarketH and MarketA have a negative ADG of -0.13%, -2.23%, -3.87% and -2.55% respectively (Table 24 in Appendix 1).

Therefore, in this case of study, considering that the time horizon is 5 years, the demand used is from 2019 to 2023. In addition, it was assumed that the monthly growth, compared to the same month of the previous year, is equal to the ADG. These considerations were made with the agreement of the company.

5.2.3. Unlimited flows, stocks and transport capacity

Given that Nespresso doesn't have its own OFCs but has signed contract with logistics operators to ensure the preparation, storage and delivery of orders, it was defined in this case study that the flows are unlimited, both in terms of units and hours, since it is intended to analyse the OFCs that should be opened, depending on the sustainability dimension analysed, without restricting it to the current volume supported. As a result, the number of hours required to prepare an order for a given market was not also differentiated and thus the same value was used for all.

For the maximum and minimum stocks, the first was stablished as unlimited and the second as zero. The definition of these values also results from not wanting to limit the options, but also wanting to obtain the costs of the network without the implication of a minimum stock, as asked by the company.

The maximum capacity of each mode of transport is assumed as unlimited both in flows between the factory and OFCs and between OFCs and markets. The first flow is considered unlimited, as this flow is Nespresso's responsibility, the intention is to deliver all necessary orders so that markets can be supplied. On the other hand, given that the flow between OFCs and the markets is carried out by the logistics operators, and they have the obligation to deliver all necessary orders, once again this value is assumed unlimited.

5.2.4. Economic Data

As described in the model formulation there are 6 types of costs associated with this case study, and all these costs presented, at Nespresso's request, are fictitious and will be presented in monetary units (MU). Transport costs obtained by Nespresso are given according to the origin and destination, not depending on the distance required to deliver the order. However, as this project is based on the sustainability of the Nespresso supply chain, considering its three pillars, these costs have been transformed in order to depend also on the distance travelled.

Therefore, the costs collected from Nespresso have been divided by the distance between each pair of entities, to obtain the transport cost per order transported and per kilometre travelled.

Regarding stock and handling cost, these only depend on the entity and the product, however, as there is no product's differentiation, in this case study, these costs are only applied to OFCs and do not depend on the contents of the order. The fixed costs of each OFC are applied when they are open. Picking costs depend on the OFC that prepares the orders and the destination market.

Lastly, the additional fixed cost is, as mentioned above, derived from a change of assets between OFCs, according to each one's operation, that is, according to the volume of orders that each OFC has assigned. In other words, in the current Nespresso network, all OFCs are used to guarantee the satisfaction of the various markets under study, and therefore, to each of these OFCs is associated a certain number of assets, such as pick to light tables, according to the orders' volume supported by each OFC. When an OFC is not used the volumes of order of other OFC increase. Thus, is necessary to move the assets that were previously allocated to a not used OFCs, to those that increase in volume. As a result, there is a cost associated to this change as well as an increase in OFC capacity. Having said that, in this case study, it was assumed by Nespresso that to a 100% increase in OFC capacity corresponds a 30% increase in fixed cost, being designated by additional fixed cost.

The values of all cost except the additional fixed cost have been determined in advance and there is no possibility of change. On the other hand, due to lack of data, the values for the additional fixed cost are assumed, based on the estimate made by Nespresso.

5.2.5. Environmental Data

In terms of environmental impacts caused by Nespresso network only the impacts of transporting orders between entities will be assessed. So, it is essential to define the modes of transport used and access the impacts caused. As already mentioned, there are 3 modes of transport, the cargo train, the cargo transport of 3.5 to 7.5 tonnes and the commercial cargo transport. According to the software used, SimaPro, for the collection of environmental data of each mode of transport, the mode that causes the least environmental impact per km travelled and per Kg transported is the cargo train, followed by cargo transport of 3.5 to 7.5 tonnes and finally, with the greatest impact the commercial cargo transport, as can be seen in Table 4, in which the normalized values are represented.

Table 4: Environmental Impact of Modes of Transport

Modes of Transport	***Normalised Values of Environmental Impact***
Cargo Transport of 3.5 to 7.5 tonnes	1.0×10^{-5}
Commercial cargo transport	1.5×10^{-5}
Cargo Train	1.4×10^{-7}

5.2.6. Social Data

To study sustainability in the social dimension, it is first necessary to know how many workers are needed in each OFC, although they do not belong to Nespresso but to the logistics operators.

Considering on Nespresso data on average one co-worker can process about 3000 orders per month. Based on this productivity, the number of employers required for each OFC depends on the total orders processed.

In addition to this parameter, it is also necessary to have the GDP and Unemployment Rate (UR) data for each country. Thus, if there is more than one OFC belonging to the same country, the values of these two parameters will be the same. Table 5 shows the values of these two parameters in each of the OFCs under study.

Table 5: Social Indicator Values by OFC (GDP per capita in PPS (2018) and Unemployment Rate in % (2019))

OFC	*1*	*2*	*3*	*4*	*5,6,7*	*8*	*9*	*10*	*11,12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*
GDP	128	118	91	112	104	123	69	71	97	153	71	77	66	121	130	156
UR	4.5	5.4	2	6.7	8.5	3.2	17	3	10	3.7	3	7	4	6.8	3.4	4.4

From this table it can be observed that at the level of GDP per capita in PPS (2018), the OFC with the lowest value in this indicator is OFC16 followed by OFC9, OFC10 and OFC14. About the Unemployment Rate (2019), the OFC with the highest value is OFC9, with 17%, followed by OFC11 and OFC12, both with 10%, and OFC5, OFC6 and OFC7, all with 8.5%.

5.3. Chapter Conclusions

In this chapter all the considerations and assumptions that had to be made in order to apply the model to the case-study under study were presented. Data concerning the Nespresso network were also presented, such as the set of entities and means of transport, as well as the processing required to obtain some parameters. To assess the sustainability of Nespresso network, some data were also presented regarding the parameters used to assess each dimension.

6. Case Study Results

The case-study problem identified in chapter 2 is solved using the mathematic model defined in chapter 4 and considering the data collected in chapter 5. This chapter aims to analyse the best networks according to each dimension in order to select one or a set of distribution networks that perform well in terms of sustainability and not just an optimal performance in an indicator. This chapter will therefore be divided into 3 phases. First, the networks will be analysed individually according to each dimension, in terms of the configuration of the allocations between OFCs and markets, and their performance in each of the indicators evaluated. Next, in view of the information gathered in the previous sections, sustainability as a whole of the distribution network will be assessed, and multi-objective analyses will be carried out in order to understand the trade-offs between economic, environmental and social performances. Finally, several scenarios that differ in the projection of demand for the following years will be elaborated, always based on the forecast given by Nespresso. All the results obtained from the different analyses have a GAP of 0.00%, except for multi-objective analysis in which GAP is 0.01%.

6.1. Sustainability Dimensions Networks

Considering the aim of Nespresso in optimise the distribution network the three sustainability goals are here analysed: economic, environmental and social. An analysis of the results obtained will also be elaborated.

When analysing Table 3, where the possible links between OFCs and markets are shown, it is possible to conclude that, without further analysis and regardless of the dimension of the sustainability analysed , MarketL has to be supplied by OFC9, MarketG has to be supplied by OFC14, MarketF has to be supplied by OFC15 and MarketA has to be supplied by OFC19. Moreover, and while the OFC9, OFC14 and OFC15 are only responsible for supplying their respective markets due to incompatibilities to other potential clients, the OFC19 may, be capable of supplying another market, within the possibilities presented and according to the network analysis dimension.

6.1.1. Economic Network

In this subsection, the aim is to optimise the network at the economic level, considering the problem characteristics and the data from 2019 to 2023 described in chapter 5.In this way, a network with a total cost of 482.6 million MU is obtained, being this cost the result of 5 years of operation. This network is characterised by a reduction in the number of open OFCs and a considerable change in OFCs-Market allocation. The economically optimal network only opens 13 OFCs and the markets allocations are provided in Table 6.

Table 6: Current and Economic Network

OFC	Market (Current Network)		Market (Economic Network)		
OFC1	MarketS				
OFC2	MarketI	MarketR			
OFC3	MarketQ	MarketB	MarketQ	MarketM	MarketB
OFC4	MarketO		MarketO		
OFC5	30% of MarketN				
OFC6	30% of MarketN				
OFC7	40% of MarketN		MarketN		
OFC8	MarketM				
OFC9	MarketL		MarketL		
OFC10	MarketK		MarketK	MarketS	
OFC11	20% of MarketJ		MarketJ		
OFC12	80% of MarketJ				
OFC13	MarketH		MarketH		
OFC14	MarketG		MarketG		
OFC15	MarketF		MarketF		
OFC16	MarketE		MarketE		
OFC17	MarketD	MarketP	MarketD	MarketP	
OFC18	MarketC		MarketI	MarketC	MarketR
OFC19	MarketA		MarketA		

Compared to the current Nespresso network only 13 allocations between OFCs and markets remain the same. Of the 6 remaining allocations, there are 4 where the OFC that supplies the market has been changed, which are the cases of the MarketM, MarketR, MarketS and MarketI. For the MarketJ and MarketN, while in the current network more than one OFC was needed to supply each market, in economic network only the OFC7 and OFC11 are opened to supply the MarketN and MarketJ respectively.

6.1.1.1. Performance of Economic Network

This subsection will analyse the economic impacts of both the current and economic network. Moreover, the impact of each type of cost on the total cost of the networks will be analysed, for 2019, with the aim of comparing the real cost occurred in that year, due to the use of the current network, with the costs that could have occurred if the Nespresso's network had been the economic one.

In 2019, the economic network described above would represent a total cost of approximately 96.4 million MU, of which 72.96% is derived from the transportation cost, 19.54% from picking cost, 5.17% from the fixed cost, 0.08% from handling cost and 2.25% from the additional fixed cost. The stock cost is equal to zero according to this dimension since there will be no product in storage between one period of time and the next.

For the predicted cost during the years 2020 to 2023, based on the expected variation in demand in each market, it is obtained that the annual total costs for 2020 would be roughly the same as the previous year. However, in the years 2021, 2022 and 2023, it is expected an annual increase in total costs of 0.008%, 0.16% and 0.25%, respectively. The representativity of each cost in the total cost of the network during each year remains unchanged, with the transportation cost continuing to have a significant weight in the economic dimension of the network.

By analysing the real costs existing in 2019, i.e., according to the current Nespresso network, with the costs of an optimised network, in that same year, it can be observed, as shown in Table 7, that it would be a reduction of 8.09% million MU. Discriminating these values by the types of cost in the supply chain under consideration, there is a 0.66% increase in transport costs, and the inclusion of an additional fixed cost that does not occur in the current network. Despite this, these increases are offset by considerable decreases in the remaining costs. Joining the two costs of opening the OFCs, the fixed cost and the additional fixed cost, the cost decreases almost 49%.

Table 7: Comparative analysis of costs between the current and the economic network

Costs in 2019	***Cost Variation (Current – Optimised)***
Network Total Cost	- 8.09%
Transportation Cost	+ 0.66%
Picking Cost	- 9.99%
Fixed Cost	- 64.26%
Additional Fixed Cost	-
Handling Cost	- 27.27%

By making the same comparison above, but considering the time horizon of 5 years and considering that the current network would remain the same during those same years, it can be seen that with a change of 6 allocations flows, which would lead to the economic network, a reduction of 42.5 million MU could be achieved, which is due to a constant reduction over the years in the some types of costs.

6.1.1.2. Additional Fixed Cost Sensitivity Analysis

Given that all types of cost, except for the additional fixed cost, are cost determined, there is a possibility that in reality the percentage previously defined in the additional fixed cost is not the correct one. Consequently, a sensitivity analysis was performed to this additional fixed cost in order to understand how it affects both the network and its total costs. Recalling that the additional fixed cost exists in the proportion that a 100% increase in OFC capacity corresponds to a 30% increase in fixed cost, it was analysed how a change in the value of the 30% would affect the economic network.

Therefore, it was observed that a change from 30% to a value below 90%, would not cause changes in the network configuration, and would only increase the total cost of the network. If the value was higher or equal to 90%, then there would be a change in the OFC supplying the MarketM, from OFC3 to OFC8. As this value is very close to 100% and very far from the expected value of 30%, it can be affirmed that the presented network is very reliable. However, if there is a deviation in the value considered, being more likely to be between 10% and 50%, there will be an impact on the total cost of the network (Table 8).

Table 8: Additional fixed cost sensitivity analysis and impact on network's total cost (in monetary units)

Additional Fixed Cost	*10%*	*20%*	*30%*	*40%*	*50%*
Network 's Total Cost	475.4	479.0	482.6	486.3	489.9

6.1.2. Environmental Network

When considering the objective as the minimisation of the environment impact (as defined in chapter 4) of the Nespresso distribution network it was observed, as expected, that the use of the train as a mode of transport was maximised as the train is the mode of transport with the lowest impact per Km travelled and per Kg transported. Therefore, given the use of this mode of transport in the orders flow between the industrial complex and OFC1 and OFC17, these OFCs will supply as many markets as possible (see Table 9), according to the possible allocations between OFCs and markets described in the Table 3, from chapter 5.

Table 9: Environmental Network

OFC	***Market***				
OFC1	MarketS	MarketQ	MarketK	MarketE	MarketB
OFC2	MarketR				
OFC8	MarketM				
OFC9	MarketL				
OFC12	MarketJ				
OFC14	MarketG				
OFC15	MarketF				
OFC17	MarketD	MarketP	MarketO	MarketH	
OFC18	MarketC	MarketI			
OFC19	MarketA	MarketN			

Accordingly, the OFC1 would supply five markets (MarketS, MarketQ, MarketK, MarketE and MarketB) while the OFC17 would supply the 4 markets (MarketD, MarketP, MarketO and MarketH) (Table 9).

The OFC9, OFC14, OFC15 and OF19 open as they are the only ones that can supply, respectively, the MarketL, MarketG, MarketF and Market A. However, it should be noted that in the OFC19 a cluster would be formed composed by the MarketA and MarketN (Table 9).

In addition to these OFCs, four more are open: OFC2, OFC8, OFC12 and OFC18,, with the first three supplying the MarketR, MarketM and MarketJ respectively, while the OFC18 would be linked to two markets, the MarketC and MarketI (Table 9).

In the case of the MarketR, the OFC2 and OFC18 can supply this market, however the supply of the orders by the OFC2 provides a shorter distance in both first and last mile, and as the modes of transport used are the same, it provides a lower environmental impact. For the same reason, the OFC8 supplies the MarketM, as the alternatives, i.e, the OFC2 and OFC3, would mean a greater distance travelled both for transport to the OFC and for transport to the customer.

Regarding the MarketJ, this can be supplied by the OFC11, OFC12 and OFC19. Between the OFC11 and OFC12, the OFC12 represents a shorter distance travelled on the two orders flows, so it will have less environmental impact, as the modes of transport used are the same. Although the OFC19 represents the shortest distance travelled in the first mile, the last mile represents an increase in the distance travelled, and as this route is carried out by the mode of transport with the greatest environmental impact, overall this allocation of the OFC19 to the MarketJ would imply a greater environmental impact than the allocation of the OFC12 to the MarketJ.

In the case of the MarketC and MarketI, the two OFCs that can supply these markets are the OFC2 and OFC18. While the allocation of the OFC2 to these markets means less distance travelled in the first mile it also means more distance travelled in the last mile. Thus, overall, as the modes of transport are the same, whether in one allocation or another, the allocation of the OFC18 to these markets provides a lower environmental impact.

As mentioned, the definition of the opening of the OFC1 and OFC17 and the consequent maximisation of the quantity of orders processed, is directly linked to the fact that the train causes less environmental impact. Nevertheless, despite this environmental data, the definition of train use is not only guided by this flow, but also by the consequent definition of the distance carried out by the commercial cargo transport in the last mile.

More precisely, per Km travelled and per Kg of cargo transported, the train causes 74 and 107 times less environmental impact than the cargo transport of 3.5 to 7.5 tonnes and commercial cargo transport, respectively. However, the train does not compete directly with the commercial cargo as the first can only be used in the first mile while the second is always used in the last mile, independent of the origin OFC and the destination market. Therefore, the use of the train in the first mile to prepare orders in an OFC far from the target market must be balanced with the longest distance travelled in the last mile by the commercial cargo, which is the mode of transport that causes the greatest environmental impact.

Given the significant difference in environmental impact caused by the train compared to the other two modes of transport considered, all the OFCs-Markets allocations in which the use of this mode of transport is allowed would be used for the definition of the environmental network, since the sum of the distances of the flows, in the first mile and in the last mile, are approximately the same whatever the route used to supply a market. Thus, it is always preferable that the first mile is made by the train when possible, although it often requires the last mile to be longer.

Compared to the economic network, from the 19 OFCs-Markets allocation to supply the 19 markets, only 8 are the same in the environmental network and correspond to the supply of the MarketL, MarketG, MarketF, MarketD, MarketP, MarketC, MarketI and MarketA. Due to the low number of equal OFCs-Markets allocations, as can be seen in the following subsection, there will be significant differences in the performance of each of these networks. This changes result in different economic performances when compared both objectives that will be analysed in the following section.

6.1.2.1. Performance of Environmental Network

Although the environmental network has the lowest impact for the environment, it is the one that would impose the highest cost for Nespresso, being 33% higher than the total cost involved in the economic network and would exceed the current cost forecast from 2019 to 2023 if the network remains the same (Table 10).

Table 10: Comparison of the performances of the Current and Environmental Networks with the performance of the Economic Network, in terms of Total Cost and Environmental Impact

	Network Total Cost (Millions MU)		**Environmental Impact**	
Economic Network	482.6	-	1958233.4	-
Current Network	525.1	+ 8.80%	1578939.7	-19.37%
Environmental Network	642.1	+33.05%	1262692.5	-35.52%

In terms of the environmental impact resulting from the different networks, the economic network is the one with the greatest impact, followed by the current network, which has 19.37% less impact compared to the economic network, and finally the environmental network, which causes 35.52% less environmental impact than the network with a lower total cost and 20.03% less than the current network (Table 10).

Concerning the environmental impact caused by each mode of transport on each of the networks, there is a set of results to be highlighted. Firstly, in both the economic network and the current network, the mode of transport that globally has the greatest impact is the cargo transport of 3.5 to 7.5 tonnes. This is not the case in the environmental network, since it is the commercial cargo transport that causes the greatest impact. This is because OFC1 and OFC17 prepare as many orders as possible due to the use of the train, in the first mile, and thus reduce the number of kilometres travelled and the orders transported by cargo transport of 3.5 to 7.5 tonnes (Table 11).

On the other hand, as it would be expected, the environmental impact caused by the train position is very residual in all the networks, but an increase in the percentage of impact caused by it translates into a considerable decrease in the environmental impact generated by the network (Table 11).

Table 11: Percentage of environmental impact caused by each mode of transport on each network

	Cargo Transport of 3.5 to 7.5 tonnes	**Commercial Cargo Transport**	**Cargo Train**
Economic Network	59.15%	40.81%	0.04%
Current Network	62.52%	37.37%	0.11%
Environmental Network	43.39%	56.38%	0.23%

6.1.2.2. *Environmental Midpoints Categories*

The environmental impact generated by each mode of transport is assessed in 18 categories linked to the human health, ecosystems and resources. Given the variety of categories assessed, there are some where the environmental impact caused by the modes of transport is greater than others (see Table 12).

Table 12: Normalised environmental impact values by category and by mode of transport

	Cargo Transport of 3.5 to 7.5 tonnes	**Commercial Cargo Transport**	**Cargo Train**
Global Warming	5,09E-08	1,81E-07	3,55E-09
Stratospheric Ozone Depletion	4,67E-09	1,52E-08	2,63E-10
Ionizing Radiation	6,08E-09	2,17E-08	1,08E-09
Ozone Formation, Human Health	1,62E-08	3,36E-07	1,47E-08
Fine particulate matter formation	8,60E-09	7,03E-08	2,31E-09
Ozone formation, Terrestrial ecosystems	1,96E-08	3,99E-07	1,73E-08
Terrestrial acidification	1,29E-08	9,76E-08	3,89E-09
Freshwater eutrophication	3,75E-10	1,49E-09	1,80E-09
Marine eutrophication	2,24E-11	4,77E-11	1,74E-11
Terrestrial ecotoxicity	5,15E-06	5,47E-06	2,28E-08
Freshwater ecotoxicity	6,74E-07	6,04E-07	6,69E-09
Marine ecotoxicity	3,73E-06	3,54E-06	2,31E-08
Human carcinogenic toxicity	7,12E-08	3,43E-06	1,70E-08
Human non-carcinogenic toxicity	5,13E-07	3,77E-07	1,60E-08
Land use	2,90E-10	1,21E-09	3,20E-10
Mineral resource scarcity	2,31E-13	9,76E-13	8,19E-14
Fossil resource scarcity	1,35E-07	4,82E-07	8,71E-09
Water Consumption	4,22E-11	4,01E-11	8,80E-10
Total	1,04E-05	1,50E-05	1,40E-07

Both in cargo transport of 3.5 to 7.5 tonnes and in commercial cargo transport, the category in which these modes of transport have the greatest impact, per Km travelled and per Kg of cargo transported, is the Terrestrial ecotoxicity followed by the Marine Ecotoxicity. In the case of the cargo train, the two categories with the greatest impact are the same, but the order is reversed. In the environmental network, these two categories with the greatest impact have a total weight of almost 71%. On other hand, it is in the Mineral Resource Scarcity category that the 3 modes of transport have the lowest impact.

Although on the whole the cargo train is the mode of transport with the lowest environmental impact generated, in two categories has the worst performance, which are in Freshwater Eutrophication and in Water Consumption categories, and in Land Use category, its performance is intermediated compared with the other two modes of transport (Table 12). The worst impact in these 3 categories is not reflected in the total environmental impact as the order of magnitude of these categories is lower than in others.

For the commercial cargo transport, in 14 categories it has the worst comparative performance, and in the remaining four categories, Freshwater Eutrophication, Freshwater Ecotoxicity, Human Non-Carcinogenic Toxicity and Water Consumption, has an intermediate performance (Table 12).

6.1.3. Social Network

Concerning the social dimension of sustainability, two indicators are analysed. According to the GDP indicator, the objective is that the OFCs are located in countries with lower GDP, and that the quantity of prepared orders is maximum in those OFCs, while according to the Unemployment Rate the objective is to locate the OFCs and maximize the prepared orders, in countries where the unemployment rate is higher.

6.1.3.1. GDP Network

By combining all the restrictions and the objective function of the GDP indicator, the network present in Table 13 is obtained.

Table 13: GDP Network

OFC	***Market***			
OFC2	MarketR	MarketI	MarketC	
OFC3	MarketM			
OFC4	MarketO	MarketP		
OFC7	MarketN			
OFC9	MarketL			
OFC10	MarketK	MarketS	MarketQ	MarketB
OFC11	MarketJ			
OFC14	MarketG			
OFC15	MarketF			
OFC16	MarketE			
OFC17	MarketD	MarketH		
OFC19	MarketA			

In this case, 12 OFCs are opened, resulting in 4 different clusters from those of the economic dimension. OFC2 prepares orders for 3 markets, OFC4 for 2 markets, OFC10 for 4 markets and OFC17 for 2 markets.

Combining the order from the lowest to highest GDP and the possible links between OFCs and markets (Table 3), since OFC16 is the OFC with the lowest GDP, this OFC is open, and supplies all the markets where it is possible to make the link, but in this case it can only prepare the orders for the MarketE. Then, there is the OFC9, which opens and supplies the MarketL, the OFC10 opens and supplies 4 markets: MarketS, MarketQ, MarketK and MarketB, and so on. OFC8, OFC1, OFC18 and OFC13 do not open, because due to the selection mechanism for opening OFCs, they no longer have any possible link, i.e. the markets that these OFCs could supply are already being supplied by OFCs with lower GDP.

As the GDP indicator values of OFC5, OFC6 and OFC7 are the same and these can supply the same market, the OFC with the best economic performance has been selected, so the one chosen to open is the OFC7. The same is valid for the OFC11 and OFC12, so OFC11 is opened.

6.1.3.2. Unemployment Rate Network

According to the Unemployment Rate indicator, a distinct network from the previous social objective is obtained. This comprises the opening of 9 OFCs, 3 of which prepare orders for more than one market (Table 14). In the case of the OFC1, it prepares orders to 5 markets (MarketS, MarketQ, MarketK, MarketE, and MarketB), the OFC2, as in the network according to GDP, prepares orders to the MarketR, MarketI and MarketC, plus the MarketM. Finally, OFC17 prepares orders to the MarketD, MarketP, MarketO and MarketH.

Table 14: Unemployment Rate Network

OFC	***Market***				
OFC1	MarketS	MarketQ	MarketK	MarketE	MarketB
OFC2	MarketR	MarketI	MarketC	MarketM	
OFC7	MarketN				
OFC9	MarketL				
OFC11	MarketJ				
OFC14	MarketG				
OFC15	MarketF				
OFC17	MarketD	MarketP	MarketO	MarketH	
OFC19	MarketA				

Under this indicator, OFCs that are located in countries with the highest unemployment rate open and maximise the quantity of orders they supply. Considering order from the highest to lowest Unemployment Rate, the OFC9 opens and supplies the MarketL, the OFC11 also opens and supplies MarketJ and so on.

In the case of OFC4, although this is one of the countries with the highest unemployment rates, the OFC does not open, as OFC17 has a higher unemployment rate and this OFC is able to supply all the markets that OFC4 can supply. In addition to the OFC4, the OFC16, OFC13, OFC10, OFC18, OFC8 and OFC3 do not open.

6.1.3.3. *Performance of Socials Networks*

For the total number of workers present on each of the social networks, this will be the same regardless of the network, since it depends exclusively on the total number of orders, given that as mentioned, it is assumed that one worker prepares on average 3000 orders per month. However, workers will be distributed differently among OFCs.

In terms of costs, these two social networks represent a higher economic effort for Nespresso compared with the economic network presented above. While the network according to the GDP indicator would increase by 3.84%, in 2019, which is equivalent to 3.7 million MU approximately, the network according to Unemployment Rate Indicator would imply an increase of 5.85% in terms of costs, which corresponds to more 5.6 million MU. Remembering that the current network in 2019 cost to Nespresso more than 104 million MU, it is interesting to note that both social networks represent a performance improve at economic level.

Looking at the time horizon studied, the costs of the networks according to GDP and the Unemployment Rate indicators would exceed 501 million and 511 million MU respectively, corresponding to an increase of 3.91% and 5.88% (Table 15). Despite this forecast increase in the total cost of the network, both social networks have a lower cost than the current network.

Regarding the performance in the social indicators of the four networks defined so far, the network according to the GDP indicator shows the best performance in that indicator, and the second best performance in the other social indicator, and the network according to the Unemployment Rate has the best performance in that indicator and the worst performance in the GDP indicator. The economic network has the second-best performance in the GDP indicator and the worst performance in the Unemployment Rate indicator, while the current Nespresso network has the third best performance in the two social indicators (Table 15).

Table 15: Social and economic performance of the networks

	Network Total Cost (Millions MU)		**GDP Indicator (points)**	**Unemployment Rate Indicator (points)**
Economic Network	482.6		24634	15786
Current Network	525.1	+ 8.80%	23045	16499
GDP Network	501.5	+ 3.91%	25043	16549
Unemployment Rate Network	511.0	+ 5.88%	22936	17771

This performance of the four networks is directly influenced by the constitution of each of the networks and consequent allocation of OFCs to markets. Therefore, the network according to the Unemployment Rate indicator is the most distinct from the others, with only 8 OFCs-Markets allocation in common with the economic network, 9 in common with the current Nespresso network, and 11 in common with the network according to the GDP indicator. On the other hand, the GDP network has 12 OFCs-Markets allocation in common with the economic network and 10 in common with the current network. In addition, both social networks have two more allocations like the current Nespresso network, but differentiated in the percentage of allocation to the OFC7 and OFC11 from demand in the MarketN and MarketJ.

Considering that the network according to the Unemployment Rate indicator has a more distinct configuration from the current network and from the economic network, this will be the only social network analysed when the multi-objective and sustainability analyses are evaluated.

6.1.4. Sustainable Network

As stated above, sustainability is a concept that embraces 3 distinct dimensions: the economic, the environmental and the social dimension. This project aims to define Nespresso's sustainable supply chain. Thus, it is intended to define a network that has the lowest cost possible, the lowest environmental impact and the highest social impact. However, as analysed in previous sections, the networks according to each dimension, are made up of different entities and also of different links between entities, which leads to conclude that there is not a perfect network, i.e. that is better in all dimensions.

To achieve the goal of this project, multi-objective analyses are developed to find the best combinations of networks that meet more than one dimension. Firstly, the economic and environmental dimensions will be analysed, followed by the economic and social dimensions. Following, the three dimensions are analysed simultaneously. The same analysis will not be prepared in order to evaluate the combinations of networks according to the environmental and social dimensions, since the economic dimension is considered the most relevant, which makes it always present in all the analyses considered.

6.1.4.1. Multi-objective analysis: Economic vs Environmental dimension

In this multi-objective analysis, the aim is to define the networks that provide the best environmental impact by defining the maximum cost of the network. In the Figure 11 all the networks that are not dominated and that promote these two dimensions are present, being evaluated in terms of additional economic impact and in terms of the decrease in the environmental impact compared to the economic network.

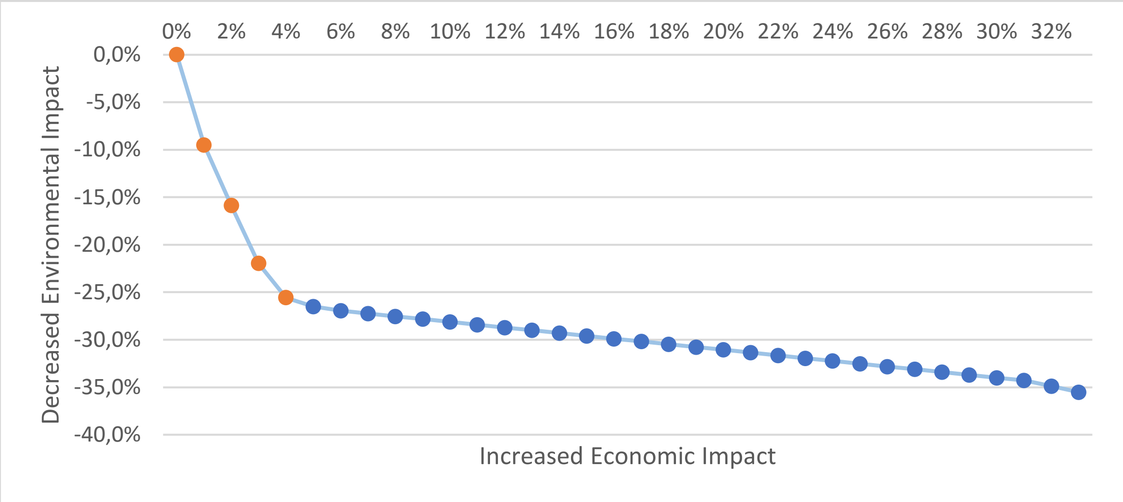


Figure 11: Multi-Objective Analysis: Economic and Environmental Dimensions

According to the graph, it is possible to highlight the existence of two groups of networks, in which the first covers the first 5 networks (orange circles) and the second group is composed by the remaining networks (blue circles). While in the first group a small variation in the total costs of the network provides a considerable decrease in the environmental impact, in the second group the same cost variation provides a slight decrease in the environmental impact. Given these characteristics, only the first group will be analysed in more detail (Table 16).

Table 16: Description of the 1st Group of Networks in Mult-objective Analysis between Economic and Environmental Dimensions

Network	Increase in Total Cost (%)	Decrease in Environmental Impact (%)	Configuration Network with Total Allocation Changes
1st	0%	0.0%	Economic Network
2nd	1%	-9.5%	Economic Network; OFC12 – MarketJ; OFC3 – MarketS
3rd	2%	-15.9%	Economic Network; OFC12 – MarketJ; OFC1 – MarketS, MarketQ, MarketK, MarketE and MarketB
4th	3%	-22.0%	Economic Network; OFC12 – MarketJ; OFC1 – MarketS, MarketQ, MarketK, MarketE and MarketB; OFC6 – MarketN
5th	4%	-25.6%	Economic Network; OFC12 – MarketJ; OFC1 – MarketS, MarketQ, MarketK, MarketE and MarketB; OFC6 – MarketN; OFC8 – MarketM

Economic Network

OFC3 – MarketS

OFC12 –MarketJ

OFC1 – MarketS, MarketQ, MarketK, MarketE and MarketB

OFC6 – MarketN

OFC8 – MarketM

The first network in the graph corresponds to the economic network, while the second network presents two changes compared to the previous one. In this second network, the MarketS in no longer supplied by the OFC10, but by the OFC3, and OFC12 opens to supply the MarketJ, which results in no opening of the OFC11. While the first change does not correspond to the environmental network, i.e., it is not a OFC-Market allocation present in that network, the second is an allocation that should be implemented according to the environmental dimension. In addition, in order to exploit the possible cost increase, in some periods of time, orders from the MarketH should be supplied by OFC17. These changes in the network lead to an increase in cost of up to 1% compared to the economic network, a decrease of 9.5% in the environmental impact generated, and the existence of 17 OFC-Market allocations in common with the economic network and 9 in common with the environmental network (Table 16).

The possibility of increasing the total cost of the network by up to 2% in the economic dimension creates the third network which, compared to the second one, promotes new network changes. According to this network, there is the opening of the OFC1 and supplies all possible markets (MarketS, MarketQ, MarketK, MarketE and MarketB). These changes bring this network closer to the environmental network, adding 5 more allocation flows in common in the two, making it 14 in total, and reducing the allocations in common with the economic network to 12. These changes result in a 15.9% decrease compared to the economic network, which, in relation to the previous network, decreases the environmental impact by more 6.4% (Table 16).

In the fourth network, which corresponds to the maximum 3% increase in the total cost of the network, there is a total decrease of 22.0% in environmental impact, which provides a further 6.1% decrease compared to the network presented above. This decrease occurs, because, compared to the previous network, another change of allocation happens, which corresponds to the supply of the MarketN by OFC6. Moreover, in most time periods, orders of the MarketH are prepared by the OFC17, however, as the change is not complete it is not considered a change of allocation. These changes, although not leading to an increase in common allocation flows with the environmental network, causes a decrease in environmental impact, and an increase in costs, which leads to a decrease to 11 of the OFC-Markets allocations in common with the economic network (Table 16).

Lastly, on the fifth network, there is a change in the network compared to the previous one concerning the supply of the MarketM by OFC8. This leads to a more 3.6% decrease in environmental impact, a maximum increase of 4% in the network total cost, and a total of 15 allocations, between OFC and markets, in common to the environmental network and 10 common to the economic network (Table 16).

In order to reach the environmental network, 4 more OFC-Market allocations would have to be changed and correspond to the supply of the MarketR, MarketO, MarketH and MarketN. These changes in the network would lead to a significant increase in the total cost of the network and a small decrease in environmental impacts, so the presence of these changes is in the second group of networks. More specifically, only when the maximum cost of network is 6% higher than in the economic network, OFC13 does not open since the orders of the MarketH are all prepared by OFC17. At the 7% increase in cost, OFC2 open and all orders from MarketR are prepared there. From the 8% maximum increase in cost, OFC19 starts to prepare orders of the MarketN in some time periods. The total change, meaning the preparation of MarketN's orders by the OFC19 in all periods of time, only happens at 32%. Finally, at 33% the last change occurs corresponding to the link of the OFC17 to the MarketO.

6.1.4.2. Multi-objective analysis: Economic vs Social dimension

The multi-objective analysis of the economic and social dimensions has the objective of defining several networks that have the best performance in these two dimensions. As previously mentioned, for determining the social network, according to each stipulated maximum value of the total cost of the network, will be used the Unemployment Rate indicator, since the network configuration that maximizes this indicator is further away from economic network configuration.

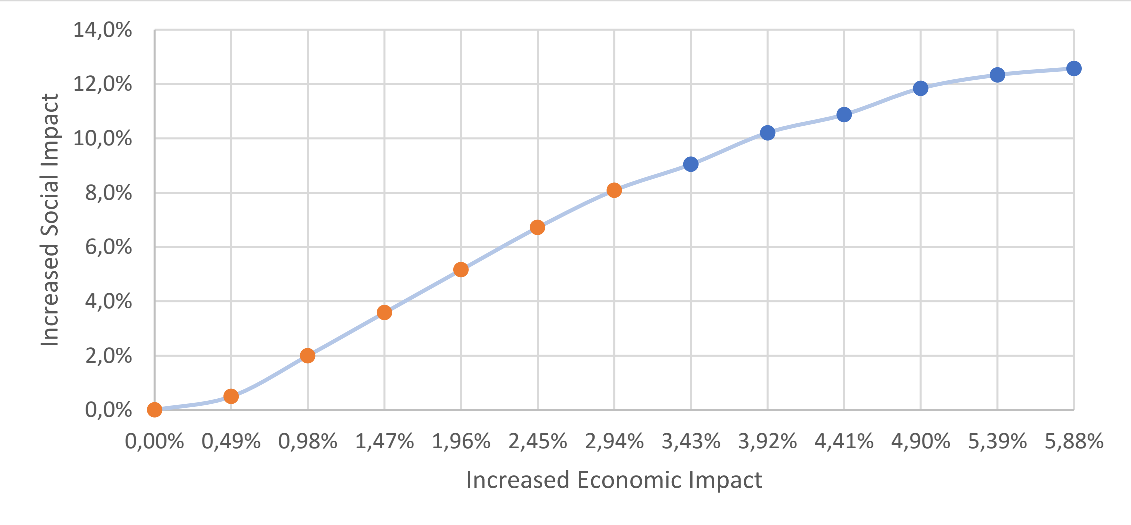


Figure 12: Multi-Objective Analysis: Economic and Social Dimensions (Unemployment Rate Indicator)

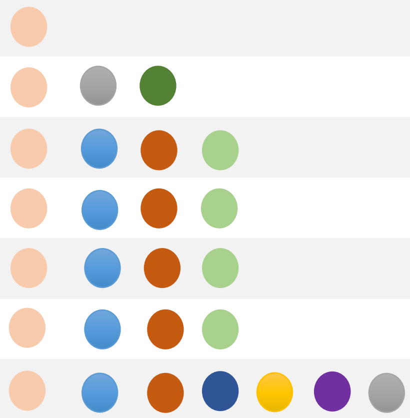
Figure 12 shows 13 networks, which include the economic network and the social network according to the unemployment rate indicator, as well as intermediate networks, in which allowing an increase in the total cost of the network leads to an improvement in the social impact, specifically in the unemployment rate indicator. From the figure it is possible to observe that the possibility of a 0.49% increase in the total cost of the network causes a slight increase in the social indicator, however, an increase between 0.98% and 2.45% leads to a constant increase in the value of the social indicator. From the maximum increase in the cost of the network of 2.94%, a decrease in the slope of the curve indicates that the percentage increase in the unemployment rate indicator is starting to get smaller and smaller, with exception of the interval between 4.41% and 5.39% where the slope increases slightly.

As stated above, the economic network and the social network according to the unemployment rate indicator have only 8 OFC-Market allocations in common, which are related to the MarketN, MarketL, MarketJ, MarketG, MarketF, MarketP, MarketD and MarketA. Thus, in order to reach the social network, it will be necessary to change 11 allocations between OFC and markets, corresponding to the orders preparation of the remaining markets, and these changes occur during the multi-objective curve.

Given this behaviour of the multi-objective curve, only the networks corresponding to the increases from 0.49% to 2.94% (orange circles) will be analysed in more detail, as they show a higher growth in the social indicator compared to the others (Table 17).

Table 17: Description of the 1st Group of Networks in Mult-objective Analysis between Economic and Social Dimensions

Network	Increase in Total Cost (%)	Increase in Social Impact (%)	Configuration Network with Total and Partial Allocation Changes
1st	0.00%	0.00%	
2nd	0.49%	0.50%	
3rd	0.98%	2.00%	
4th	1.47%	3.58%	
5th	1.96%	5.16%	
6th	2.45%	6.71%	
7th	2.94%	8.08%	



In the network corresponding to the increase up to 0.49% in cost, the open OFCs remain the same as in the economic network, however, additionally, OFC10 prepares orders from the MarketQ, and OFC17 prepares orders from the MarketH, in some periods of time, without a complete change in allocation flow. Therefore, although the change on the MarketQ in this network does not lead to an increase in the number of OFC-Market allocations in common with the social network, it leads to a decrease in the number of allocations in common with the economic network to 7. These changes lead to an increase of 0.50% in the social impact compared to the economic network (Table 17).

In the third network of the value concerning the increase of up to 0.98% in the total cost of the network, there is a significant increase of 1.50% in the social impact generated by the opening of the OFC2 and its preparation of orders from the MarketR and MarketI and the MarketM, only in a few periods of time. Moreover, the MarketQ is again supplied by OFC3, and OFC13 prepares all orders from the MarketH. The latter allocation changes, concerning the MarketQ and MarketH, correspond to an increase in the number of allocations in common to the economic network. If previously, in the network of the 0.49% increase in cost, these changes for these two markets led to an increase of 0.50% in social impact, the backward step of these changes is also a 0.50% decrease in social impact, which means that the change of allocations only in the MarketR, MarketI and MarketM leads to an increase of 2.00% in social impact. This change, although quite significant, does not occur on the previous network, as the cost of this change is higher than allowed on that network. Regarding the returns in the other markets, this occurs because although they cause a decrease in social impact, they also decrease the cost associated with the network, which allows the remaining changes in the network to occur (Table 17).

In the networks corresponding to the increase in total cost of 1.47%, 1.96% and 2.45%, there is an increase in social impact of 3.58%, 5.16% and 6.71% respectively, which provides a constant increase of approximately 1.6% in social impact. In these 3 networks, compared to the previous network, there are only changes concerning the MarketM, where the number of periods in which this market is supplied by the OFC2 increases successively (Table 17).

When an increase of up to 2.94% in the total cost of the network is allowed, OFC2 prepares orders from the MarketM in all time periods, and in some time periods, prepares orders from the MarketC. In addition, OFC10 supplies MarketQ and MarketB. Given these changes, this network has 11 OFC-Market allocations in common with the social network, plus one more partial allocation from the MarketC (Table 17).

Until the social network is achieved, the total cost needs to be increased by 5.88%, which translates into changes in the allocations of the MarketS, MarketK, MarketQ, MarketB, MarketE, MarketO, MarketH and MarketC. At 3.92% orders for the MarketC are prepared by OFC2, at 4.90% the OFC1 opens and prepares orders for the MarketS, MarketQ and MarketB, at 5.39% the MarketK is supplied by OFC1 and the MarketH is, in most periods of time, supplied by OFC17, and at 5.88% the remaining changes concern the MarketO, MarketH and MarketE.

6.1.4.3. Multi-objective analysis addressing the three dimensions of sustainability

To analyse the three dimensions of sustainability simultaneously, a multi-objective analysis integrating these dimensions has been developed. Through this analysis , 54 different networks were obtained, as can be seen in Figure 13, which consequently have different impacts on the various sustainability indicators. Furthermore, for the evaluation of the social dimensions, only the Unemployment Rate indicator was considered, since the network that maximizes this indicator is more differentiated from the economic network.

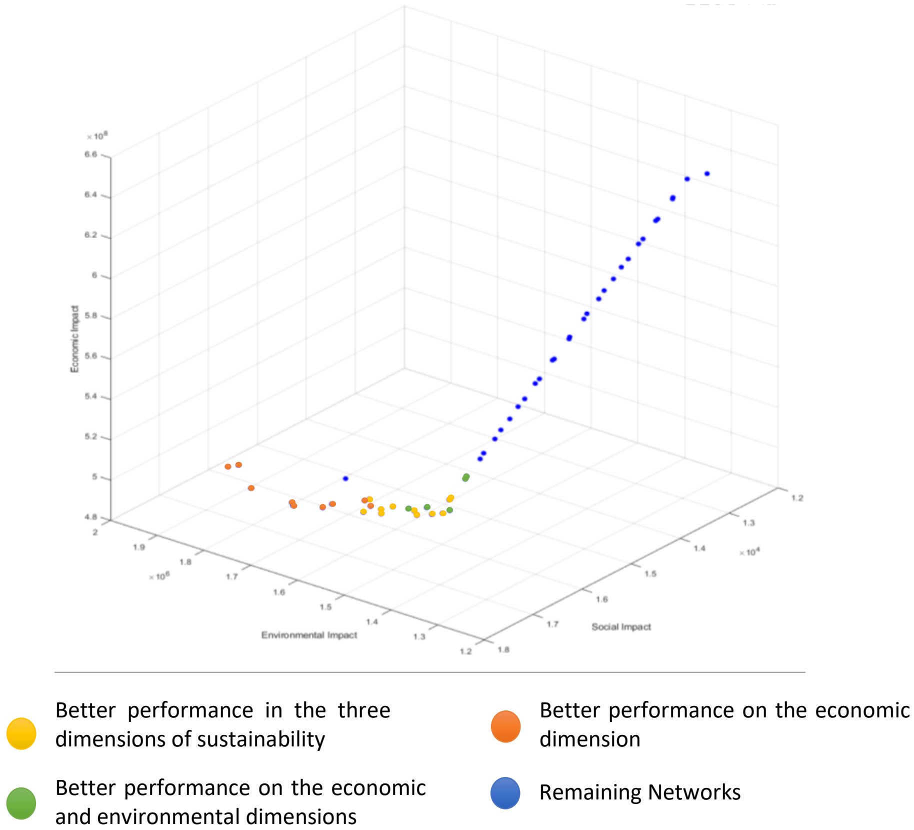


Figure 13: Multi-Objective Analysis: Economic, Environmental and Social Dimensions

The analysis of the Figure 13 shows that from a certain point onwards, all represented networks present a proportional variation of performance in the three dimensions of sustainability, i.e., given the percentage increase in cost, all the networks show a proportional decrease in both the environmental and social impacts. The existing differences in the impacts of these networks are due mainly to the supply transition of both MarketO and MarketN. More specifically, the networks present in this area which have the highest economic impact, and consequently the lowest environmental and social impacts, result from the OFC19 supplying the MarketN in most periods of time and the OFC17 supplying the MarketO in most periods of time. On the other hand, in the networks in this area which have better economic and social impacts and higher environmental impact, most of the periods of time, the MarketN is supplied by OFC6, and the MarketO by OFC4.For the remain allocation, in most of the networks, they are the same as those in the network which optimises the environmental dimension.

Moreover, the remaining networks, which do not show the proportional performance variations, show greater differences in market allocations to OFCs, being all characterised by an economic impact less than 540 million MU, and environmental impact of more than 1.4 million impact points and a social impact of more than 15700 impact points.

Of the 54 networks shown in the Figure 13, only 25 have a lower cost than the current Nespresso network (yellow, orange and green circles), all having in common the allocation of the MarketL, MarketG, MarketF and MarketA to, respectively, OFC9, OFC14, OFC15 and OFC19, and the MarketD and MarketP to the OFC17.

Analysing the networks that perform better on the economic and environmental dimensions than the current networks, only 16 verify these conditions (yellow and green circles), and in addition to the common allocations previously presented, it emerges that in all networks the MarketS, MarketQ, MarketK and MarketB are supplied by OFC1, and the MarketJ by OFC12. Regarding a better performance in the three dimensions of sustainability in relation to the expected performance of the current network, only 11 networks satisfy this status (yellow circles), and no more common allocation are added to those mentioned above.

6.2. Scenario analysis

In all the analyses elaborated and previously shown, a deterministic problem was solved considering the demand characterized by the demand forecasting data provided by Nespresso. However, due to the uncertainty associated with predicting demand in future years, different scenarios should be considered. These are below analysed.

6.2.1. Definition of the scenarios analysed and their probabilities

The analysis performed considers a baseline scenario, which expresses the demand forecast developed by Nespresso. This scenario is assumed to have a 50% probability, which is higher than the probability of occurrence of the remaining scenarios, because this scenario is built on the data collected by Nespresso in each of the markets considered (Figure 14). However, taken this scenario as basis, there are markets where demand is expected to increase while in others, demand is expected to decrease. In total, there are 5 markets where annual demand is predicted to decline, and these include the 3 markets with the highest volume of orders, MarketN, MarketM and MarketA, which globally account for more than 50% of orders volume. To these are added the MarketP and MaketH, where the order volume of each represents only 1% of the total volume.

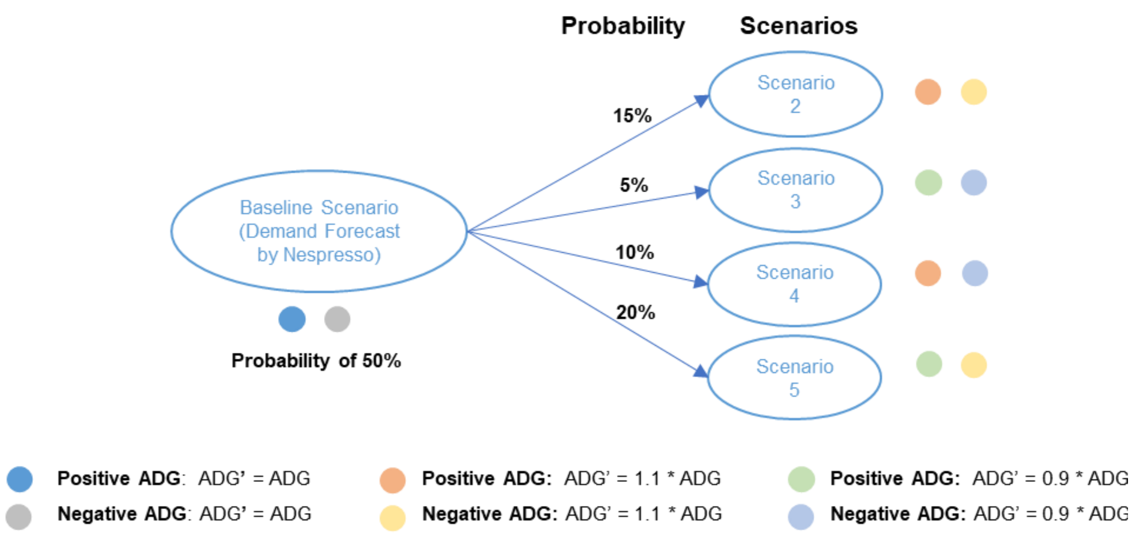


Figure 14: Scenarios

The second and third scenarios correspond, respectively, to the increase and decrease of the proportion in 10% of the annual growth predicted. In other words, in the second scenario, in markets where annual demand is expected to increase in, the increase is 10% higher, and in markets where annual demand is expected to decrease, the decrease is 10% higher. In third scenario, the opposite happens, i.e., in markets where an increase in demand is forecast in baseline scenario, the increase is 10% smaller, and in the remaining markets, the decrease is also 10% smaller. The probability of occurrence of these scenarios is respectively 15 and 5% (Figure 14).

Finally, in the fourth and fifth scenarios, the annual volume of orders in each market is higher or lower than in baseline scenario. That means that in the fourth scenario it is considered that in countries where demand is expected to increase is 10% higher, and in the remaining markets, the decrease is expected to be 10% lower. On the other hand, in the fifth scenario, it is assumed that in all markets the expected demand is lower than in the baseline scenario, more specifically, in those markets where an increase is expected this increase is 10% lower, and in those where a decrease is expected it is 10% more pronounced. The existence of the fourth scenario comes from the possibility that coffee consumption may be higher at home compared to previous periods, given the current moment crossed by all countries and the restrictions imposed in each. In another sense, there is the fifth scenario that may be caused by the decrease in household consumption due to the uncertainty of future economic conditions caused by the pandemic. It was assumed a probability of occurrence of these scenarios of 10% and 20% respectively (Figure 14).

Data concerning the annual demand growth (ADG) by market in each scenario are shown in Table 25 in Appendix 2. With these data, it is intended to assess whether the configuration of each networks in each of the dimensions will change, and if so, which allocations can be changed according to the forecast demand.

6.2.2. Analysis of the results obtained

According to the scenarios defined and their probability, it is verified that in terms of economic dimension, the OFC-Market allocations that minimize the total cost of the network are the same, with only few differences in the values predicted in the various indicators analysed. Regarding the total cost of the network, there is a reduction of 0.025%, in environmental impact the reduction is 0.019% and in both social indicators there is a reduction of almost 0.02% (Table 18).

Considering the environmental dimension, the network that minimizes the impact in this indicator is also composed by the same OFC-Markets allocations as when analysing only one scenario. Comparing the performance in each indicator, a maximum reduction of 0.025% is observed in each one (Table 18).

In terms of the social dimension, in both indicators the network remains the same, however some fluctuations in the values of the indicators analysed are observed. While according to the GDP, there is a decrease of 0.025% in total cost of the network, according to unemployment rate indicator, this decrease is 0.026%. Regarding the performance of these networks in the remaining indicators, there is no significant change and the reductions do not reach 0.025% (Table 18).

Table 18 : Performance change in the sustainability indicators with uncertainty analysis

	Network Total Cost	***Environmental Impact***	***GDP Indicator***	***Unemployment Rate Indicator***
Economic Network	*- 0.025%*	*-0.020%*	*- 0.019%*	*- 0.016%*
Environmental Network	*- 0.021%*	*- 0.021%*	*- 0.025%*	*- 0.022%*
GDP Network	*- 0.025%*	*- 0.019%*	*- 0.024%*	*-0.015%*
Unemployment Rate Network	*- 0.026%*	*- 0.019%*	*- 0.021%*	*- 0.021%*

The reduction in each indicator in each of the analyses prepared according to the dimensions of sustainability, and the unchanged OFC-Market allocations in each of these networks, result only from the slight general decrease in demand in each market considering the 5 scenarios and the probability of occurrence of each one.

6.3. Chapter Conclusions

In this chapter, the model described in chapter 4 using the data described in chapter 5 is applied to the case study of Nespresso. The various networks that perform optimally in one indicator are described. According to these analyses, it was observed that there is no optimal distribution network at all the sustainable dimensions, but with compromises in some indicators, can be obtained networks with good performance in more than one indicator. The development of scenarios for demand uncertainty has confirmed that the network is robust if actual demand in the coming years does not match forecast demand.

7. Recommendations

This chapter aims to present and recommend one or more networks that perform well in the three dimensions of sustainability, with only the Unemployment Rate indicator being considered in the social dimension, since between the two social networks, the network that maximizes the Unemployment Rate indicator has a more distinct configuration from the economic network. To do this recommendation, only deterministic values were used since, as demonstrated in chapter 6, the configuration of the networks would not change, and would make this analysis more complex. Having this objective in mind, the chapter is divided into three parts, in which first the OFC-Market allocations in common in the three dimensions of sustainability will be analysed, then from the graphs elaborated for the multi-objective analyses recommendations will be given on which allocations should be carried out. Finally, several networks will be presented which show a good performance in the indicators, but which differ in the allocations considered.

7.1. Common OFC-Market Allocations

Analysing the 3 networks, each referring to the optimisation of one sustainability dimension, it is possible to observe that there are 6 OFC-Market allocations in common to all. These concern the MarketL, MarketF, MarketG, MarketA, MarketD and MarketP. Therefore, these 6 allocations are present in any networks with a good performance in all indicators, so in sustainable network the supply of these markets will be carried out by the OFCs mentioned. The remaining 13 markets, although they are not supplied by the same OFC in the 3 networks, as can be seen in Table 19, there are allocations in common between each two dimensions.

Table 19: OFCs that supplies the 13 markets according to each sustainability dimension

Market	Economic OFC	Environmental OFC	Social OFC
MarketS	OFC10	OFC1	OFC1
MarketR	OFC18	OFC2	OFC2
MarketQ	OFC3	OFC1	OFC1
MarketO	OFC4	OFC17	OFC17
MarketN	OFC7	OFC19	OFC7
MarketM	OFC3	OFC8	OFC2
MarketK	OFC10	OFC1	OFC1
MarketJ	OFC11	OFC12	OFC11
MarketI	OFC18	OFC18	OFC2
MarketC	OFC18	OFC18	OFC2
MarketH	OFC13	OFC17	OFC17
MarketE	OFC16	OFC1	OFC1
MarketB	OFC3	OFC1	OFC1

From Table 19, it emerges that the OFCs supplying the MarketS, MarketR, MarketQ, MarketO, MarketK, MarketH, MarketE and MarketB are the same in the environmental and social networks. Between the economic and social, there are more two allocations in common, concerning the MarketN and MarketJ, and between the economic and environmental dimensions, here are also two more allocations in common, relating to the supply of the MarketC and MarketI. On the other hand, the MarketM is the only one where according to each dimension there is a different allocation, to improve the evaluated indicator.

7.2. Defining the OFC-Market Allocations

In this subsection, some OFC-Market allocations will be defined based on the multi-objective analyses realised and based on the similarities in the networks according to each dimension.

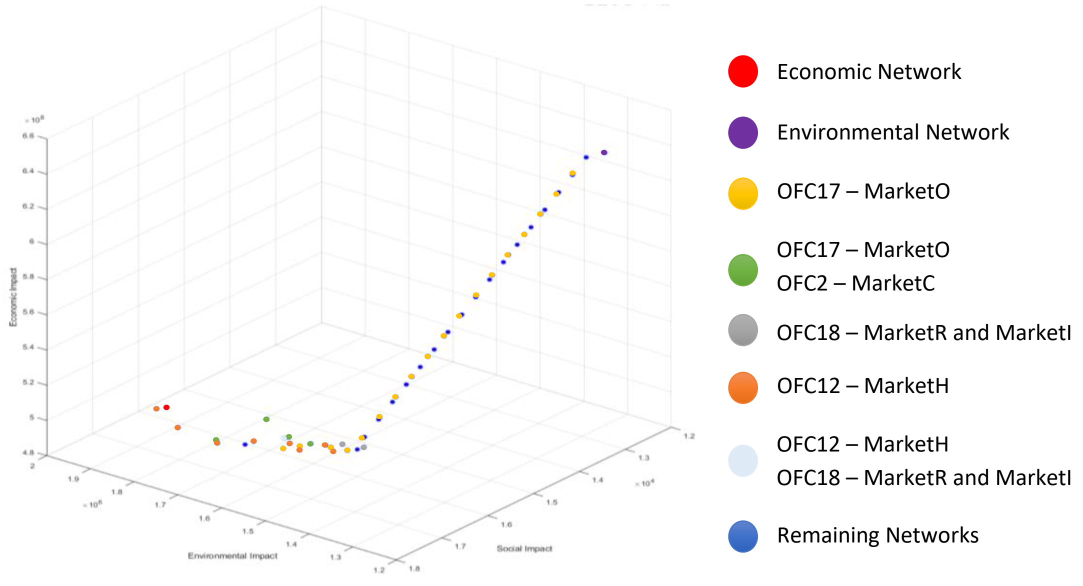


Figure 15: Multi-Objective Analysis of the Three Dimensions of Sustainability and Networks Allocations

Starting with the MarketO and MarketC, although the allocations differ according to the indicators evaluated, none of these changes is verified in the areas analysed in more detail in the two-dimensional multi-objective graphs. This indicates that the ratio between social and/or environmental benefit generated by this change and the increase in the total cost of the network is lower than the ratio for other allocations changes. Moreover, in the multi-objective analysis incorporating the 3 dimensions of sustainability, the change of allocation from the MarketO to the OFC17 only occurs in 23 networks (purple, yellow and green circles), and from the MarketC to the OFC2 only occurs in 4 networks (green circles), with the minimum cost of these networks being respectively 5.53% and 6.28% higher than in the economic network (Figure 15). Consequently, it is defined that orders from the MarketO will be prepared by OFC4 and orders from the MarketC by OFC18.

For the MarketH, it is also defined to maintain the allocation present in the economic network for similar reasons as in the two previous markets. Although in both environmental and social networks the best option for supplying this market is OFC17, in two-dimensional multi-objective analyses the change of allocation is never complete, so again it indicates that the ratio of this change is lower than in others. Considering the analysis of the three dimensions and the two previously defined allocations, maintaining the economic allocation to this market (red, orange and light blue circles) means that the economic impact does not exceed more than 4.96%

compared to the economic network (Figure 15). Regarding the other two dimensions, in 8 out of 10 networks which check these allocation, there is a decrease of more than 15% in environmental impact, and in 8 out 10 networks there is an improvement of 3.23% or more in social impact, comparing with the economic network.

The preparation by the OFC1 of orders from the MarketS, MarketQ, MarketK, MarketE and MarketB reflects an improvement in both environmental and social impact. Additionally, this change is present in the two-dimensional multi-objective analyses between the economic and environmental dimension, indicating that the increase in cost is offset by the large improvement in the environmental indicator. Furthermore, as seen in the analysis of the multi-objective graph that considers the three dimensions of sustainability, with exception of the MarketE, the allocation of the remaining 4 markets is common both in the networks with best economic and environmental impact, and in the networks with best performance in the three dimensions, compared to the current to the current Nespresso network. The inclusion of the allocation of the MarketE to the OFC1 provides a better performance at both environmental and social levels. Thus, the implementation of this change in the economic network would improve the environmental impact by 8.58%, improve the social impact by 1.72% and increase the total cost of the network by 6.6 million of MU, which is equivalent to only 1.36%. In view of these values, the sustainable network will include these 5 OFC-Market allocations.

Similarly, the MarketR according to the environmental and social networks, would be supplied by the OFC2, while in the economic network would be supplied by the OFC18, and this change is present in the multi-objective analysis between the economic and social dimensions. In terms of the MarketI, the change of allocation only occurs in the social network. The preparation by the OFC2 of the orders on the MarketR would provide a decrease of 0.41% in the environmental impact, an improvement of 1.27% in the social impact and an increase of 0.81% in the total cost of the network, compared to the economic network already with the 5 previous allocations. However, if the change is in both markets, the environmental impact would also decrease by 0.41%, the social impact would improve by 1.34% and the total cost of the network would increase by 0.79%. Given these data and as 49 of the 54 networks in the three-dimensional multi-objective is present the allocation of both markets to the OFC2 (all networks except those in the red, purple, grey and light blue circles), a change in both markets is preferable (Figure 15). So, the small increase in the total cost of the network would promote a slight improvement in the environmental indicator and would promote a considerable improvement in the social indicator. Thus, the MarketR and MarketI will be supplied by the OFC2 in the sustainable network.

In the multi-objective analysis between the economic and environmental dimensions, there is a change of OFC that prepares the orders of the MarketN for OFC6. In addition, the partial or complete supply of the OFC6 to the MarketN is verified in 44 networks out of 54 in the multi-objective analysis of the three dimensions, improving the performance in the environmental dimension. On the other hand, in the same multi-objective analysis, it is verified that in 9 of the networks, the allocation of this market should be to OFC7, potentiating a better economic performance. As this change does not affect the social level, since both OFC7 and OFC6 have the same value in the unemployment rate indicator, the choice for a particular OFC is limited to the preference between a better environmental or economic performance. Moreover, although the network that optimizes the environmental dimension is present in the allocation of this market to the OFC19, it is clear from the multi-objective analysis of the 3 dimensions that the allocation in most periods of time of this OFC to this market, results in networks with higher cost and also with a worse social performance than the current network. So, this is not considered a possible allocation to the sustainable network.

For the MarketJ, as shown in Table 19 according to the environmental dimension the choice would go to the OFC12, and it is verified that this change, compared to the economic scenario, would occur in the second network of the multi-objective analysis of the economic and environmental dimensions (Table 16).

From the multi-objective analysis of the 3 dimensions, only 2 of the 54 networks have the allocation of the MarketJ to OFC11. In addition, this change would not have negative impact on social dimension, as the social indicators of the two OFCs are the same. Based on these data, the choice of one OFC over another is directly related to the choice of a network with lower total cost or lower environmental impact.

Finally, the MarketM according to each dimension is supplied by a different OFC, and these allocation changes are present in both multi-objective analyses, indicating that the ratio between the environmental or social benefit and the additional cost of the network is better compared to other OFC-Market allocation changes. The partial or complete allocation of this market according to the social dimension, is present in 10 of the networks represented in the three-dimensional multi-objective analysis, while the allocation according to the environmental network is present in 39 networks. The remaining networks include the allocation according to the economic dimension.

Given the characteristics involved in the MarketN, MarketJ and MarketM, these allocations alternatives will be analysed in the following subsection where different combinations will be formed, and the performance of each of these networks will be analysed in the sustainability indicators in order to find one or a set of networks that are sustainable and that depend exclusively on the option of having a network with better economic, environmental or social performance.

7.3. MarketN, MarketM and MarketJ

According to the previous statements, of the 19 markets that need to be supplied, only the OFCs that supplies the MarketN, MarketJ and MarketM remains to be defined. In view of the various options for each, combinations will be developed and the impact of these will be assessed in the indicators evaluated. Table 20 shows the OFC-Market allocations of the markets already defined.

Table 20: OFC-Market Allocations of the Sustainable Network

OFC	Market				
OFC1	MarketS	MarketQ	MarketK	MarketE	MarketB
OFC2	MarketR	MarketI			
OFC4	MarketO				
OFC9	MarketL				
OFC13	MarketH				
OFC14	MarketG				
OFC15	MarketF				
OFC17	MarketD	MarketP			
OFC18	MarketC				
OFC19	MarketA				

For the remaining markets, given that the allocations of the 3 markets are undefined , in Table 26 of the Appendix 3, the combinations of networks are present, and it can be seen that there are 3 combinations that are dominated, which are the seventh, ninth and eleventh that are dominated respectively by the second, fourth and sixth combinations of networks. The dominated combinations perform worse on the economic and environmental indicators and have the same performance on the social indicator. So, these dominated combinations are not considered as possible to be used on the sustainable network.

Consequently, the nine remaining combinations, perform better in some indicators and worse in others, making it possible for each of them to integrate the sustainable network. The choice of one over the other results only from the desire to achieve better economic, environmental, or social performance, or by giving preference to only two of the three dimensions of sustainability.

Considering that the economic impact is considered indispensable in the analysis and choice of the sustainable network, and if the environmental dimension is considered more relevant for the decision than the social dimension, being the latter dimension considered the least relevant and therefore disposable, there will be only four networks that are not dominated that correspond to the first, second, eighth and tenth. Of these four combinations, the first results in better economic performance and worse environmental performance, while the tenth results in a better environmental performance and worse economic performance. The two remaining networks show intermediate performance, with the second performing second best in economic indicator and the eighth performing second best on the environmental indicator (Table 21).

Table 21: OFC-Market Allocation with better Economic and Environmental Performance

OFC-Market Allocation	MarketN	MarketM	MarketJ	Economic Impact (M MU)	Environmental Impact
First	OFC7	OFC3	OFC11	493.2 (+ 2.20%)	1782985 (- 8.95%)
Second	OFC7	OFC3	OFC12	494.6 (+ 2.49%)	1651982 (- 15.64%)
Eight	OFC6	OFC3	OFC12	499.0 (+ 3.40%)	1536518 (- 21.54%)
Tenth	OFC6	OFC8	OFC12	504.6 (+ 4.56%)	1460035 (- 25.44%)

Based on these data, of the four networks, since the first has a considerable difference in environmental impact and the tenth requires a high increase in total cost, these two combinations should not be considered in the sustainable networks. Furthermore, the second and eighth combinations only differ in the OFC supplying the MarketN, as both are characterised by the

OFC3 supplying the MarketM and the OFC12 supplying the MarketJ. Therefore, the second, with the OFC7 provides a better economic impact, while the eighth, with the OFC8 provides a better environmental impact. The choice between one or the other depends on the decision for a more economical or more environmental network (Table 21).

Moreover, if there is a higher importance of the social indicator, and consequently a lower importance of the environmental indicator, while the economic indicator remains indispensable, only the first, third and fifth combinations of networks can be options for sustainable networks, since the rest are dominated. In these three networks, the MarketN is supplied by the OFC7, and the MarketJ by the OFC11, so they differ in the option of the OFC supplying the MarketM. So, the selection of a combination depends on the choice between a better economic performance, a better social performance, or an intermediate value in both indicators (Table 22).

Table 22: OFC-Market Allocation with better Economic and Social Performance

OFC-Market Allocation	*MarketN*	*MarketM*	*MarketJ*	*Economic Impact (M MU)*	*Social Impact*
First	OFC7	OFC3	OFC11	493.2 (+ 2.20%)	16262 (+ 3.02%)
Third	OFC7	OFC8	OFC11	498.8 (+ 3.36%)	16612 (+ 5.23%)
Fifth	OFC7	OFC2	OFC11	501.7 (+ 3.96%)	17254 (+ 9.30%)

Remembering that this project was originated in the desire to reduce the costs in the distribution network given the growth of the Nespresso coffee capsules market, it can be assumed that the economic dimension is considered the most relevant for Nespresso. In order to choose the Nespresso distribution network it is extremely important to know the relevance of the remaining dimensions to stablish a hierarchy of sustainability dimensions, as well as to assess the existing trade-offs, and to understand what cost increase Nespresso is willing to have to achieve a more environmentally and socially sustainable network.

The choice of any of the distribution networks presented in Table 21 and Table 22 combined with the 16 OFC-Market allocations already established, provide a total cost increase and a performance improvement in the other dimensions, compared to the network that optimises the economic dimension. By comparing with the current Nespresso distribution network, it is possible to notice that these networks perform better on the economic dimension. Regarding the environmental dimension, only the eighth and tenth combinations have better perform, while in the social dimension, only the third, fifth and tenth combinations of OFC-Market allocations represent a better performance than the current network.

In conclusion, although the economic dimension is considered to be crucial to this analysis, the choice should not focus on the network that optimises this dimension, due to the consequent poor performance in the other indicators. On the other hand, the definition of the 16 allocations as demonstrated in the previous subsection, allows Nespresso to obtain a network with better environmental and social performance, increasing the cost slightly. Although, the choice of the remaining allocations depends exclusively on Nespresso's preference, I will suggest a network that performs well on the three indicators evaluated.

The 16 OFC-Market allocations described above, provide a better performance on both environmental and social indicators, so in the choice of the remaining three allocations, preference will be given to environmental impact. Thus, as described in Table 21, only four networks are not dominated. Elaborating a ratio between the percentage decrease in environmental impact generated by each network and the percentage increase in total cost, it can be observed that comparatively, the first and tenth combinations have a lower ratio, being respectively 4.07% and 5.57%, that the second (6.28%) and (6.33%) eight combinations. Consequently, the first and tenth combinations should not be chosen, although among the four, they represent the best combination in the economic and environmental indicator respectively.

The choice of the second or eight combination of allocations implies that the MarketM is supplied by the OFC3, and the MarketJ is supplied by OFC12, with the latter allocation being present in the set of common allocations of the networks with the best performance in the three dimensions, as verified in the multi-objective analysis of the three dimensions of sustainability. On the other hand, they are differentiated by the allocation of the OFC to the MarketN.

Despite the closeness of the ratios of these two combinations, since the eighth is the only one that presents improvements in the environmental performance compared to the current network, this combination is preferable although the slight increase in the total cost of the network. When comparing this combination with the networks in the multi-objective analysis that incorporates the three dimensions of sustainability, it can be noted that there is a network very similar to this one, which is only distinguished by the allocation of the MarketE. While in the chosen combination the MarketE is supplied by OFC1, in the multi-objective analysis network this market is, in most of the time periods considered, allocated to the OFC16. The allocation to OFC1, despite the slight increase in total cost, brings an improvement at the environmental and social level. Table 23 shows all OFC-Market allocations in this suggested network.

Table 23: Recommended OFC-Market Allocations

OFC	***Market***				
OFC1	MarketS	MarketQ	MarketK	MarketE	MarketB
OFC2	MarketR	MarketI			
OFC3	MarketM				
OFC4	MarketO				
OFC6	MarketN				
OFC9	MarketL				
OFC12	MarketJ				
OFC13	MarketH				
OFC14	MarketG				
OFC15	MarketF				
OFC17	MarketD	MarketP			
OFC18	MarketC				
OFC19	MarketA				

As shown, this network consists of 13 OFCs to supply 19 markets, with 3 clusters, centred in OFC1, OFC2 and OFC17. Compared to the current Nespresso network, the suggested network keeps 12 OFC-Market allocations equal, differentiating in allocations to the MarketK, MarketQ, MarketB, MarketE, MarketN, MarketJ and MarketM. Recalling that the current Nespresso distribution network represents a total cost of 525.1 million MU, the recommended network allows savings of 26.1 million MU (4.82%). In environmental indicator, it represents a decrease of 2.69%, and according to Unemployment Rate indicator, it represents a loss of 1.37%.

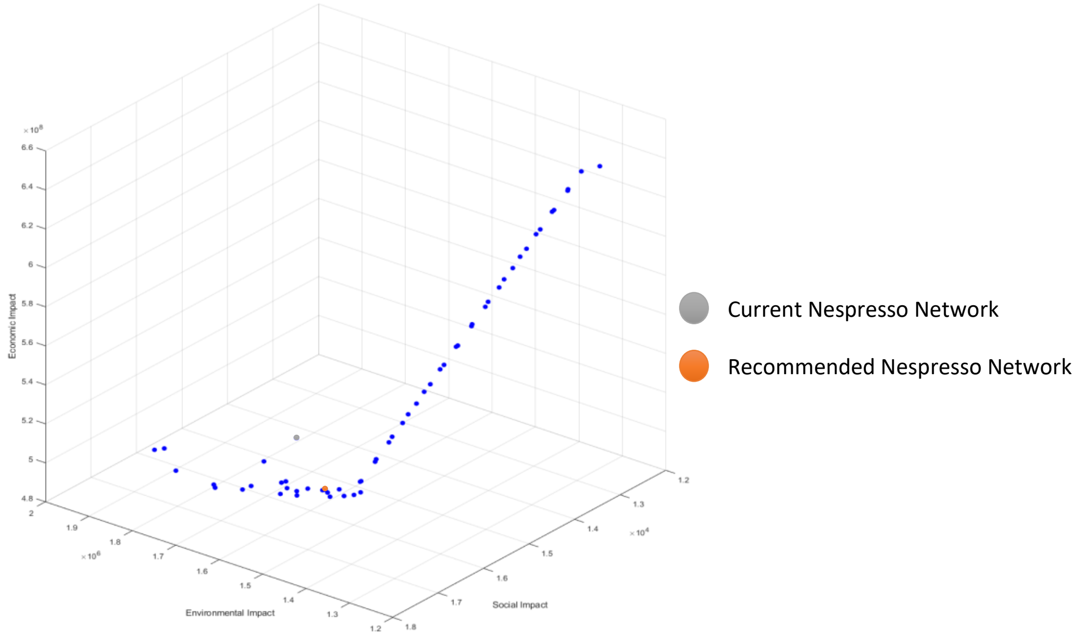


Figure 16: Current and Recommended network positioning in multi-objective analysis

7.4. Chapter Conclusions

The main objective of this chapter was to define several sustainable networks, as they perform well in the various indicators. However, given the analyses made, it can be seen that there is no network that presents the best performance in all of the indicators. However, it could be seen that through the analysis of the multi-objective graphs and the hierarchy of the sustainability dimensions it is possible to reduce the number of network combination and verify in which OFC-Market allocations they differ.

To this end, it has always assumed that the economic dimension is very relevant to the choice of network, and that between the two remaining dimensions there is no declared preference, as it depends on Nespresso's vision of the importance of each. Consequently, the best networks have been reported according to the preference between the social and environmental dimensions. Finally, a network with good performance in all indicators is recommended, which is characterized by the opening of 13 OFCs and with the following OFC-Market allocations: OFC1 supplies MarketS, MarketK, MarketQ, MarketE and MarketB; OFC2 supplies the MarketR and MarketI; OFC17 supplies MarketP and Market D; OFC4 supplies MarketO; OFC6 supplies MarketN, OFC9 supplies MarketL; OFC12 supplies MarketJ; OFC14 supplies MarketG; OFC15 supplies MarketF; OFC18 supplies MarketC; OFC19 supplies MarketA; and finally, OFC3 supplies the MarketM. Through this network, an improvement of 4.82% in the economic dimension, and of 2.69% in the environmental dimension are achieved, and a slight loss of 1.37% in the social dimension.

8. Conclusions and Future Work

To advise Nespresso to have a sustainable distribution network, a strategic and tactical model has been developed that considers the three dimensions of sustainability. Accordingly, it is intended to define which OFCs should be used and which markets they should supply in order to obtain a sustainable supply chain. Therefore, the aim is to find an optimal network or a set of networks that provide comparatively good performance at the 3 dimensions analysed.

The literature review aimed to define the main concepts, according to different authors, in order to frame the existence of sustainability in supply chains. Following this, a set of optimization models with different characteristics were presented, addressing differently the pillars of sustainability, forward logistics or closed loop supply chain. From the selected models, only two portrays the three pillars of sustainability, with the rest either looking at design and planning with the aim of only minimizing costs, or also looking at the environmental pillar, always giving more focus to the economic pillar. In addition, in the research carried out, no models were found applied in companies that manufacture coffee capsules.

In this way, the Mota et al. (2018) model was selected to serve as the basis for the model that is used and applied in this case study, since of the two models addressing all sustainability dimensions, this is the only one that allows the assessment of the uncertainty associated to demand. However, by choice of Nespresso, reverse logistics was not considered in this work. This model evaluates the supply chain at both the strategic and tactical level, as at the first level it includes decisions regarding the number and location of OFCs, an at the tactical level it includes decisions concerning the flow of products.

Given the variety of Nespresso products and the variety of customers, the complexity inherent to this work is quite considerable. Consequently, in order to reduce this complexity, it was necessary to adopt strategies that allow a lower computational impact and that do not compromise the results obtained. Thus, it was necessary to aggregate the customers by country and only one type of product was considered, the order.

Through the data collected and the adaptation of the model to the case study, it was possible to verify the optimal network according to each sustainability dimension. The analysis of the optimal networks according to each dimension allowed to assess the differences and similarities at the strategic and tactical level. In the light of these evidences, new analyses were developed to analyse the impact on the social and environmental dimensions of the variation in the total cost of the network. In addition, a number of scenarios was developed to assess the uncertainty associated to the Nespresso demand and to establish the robustness of the networks developed.

Considering these analyses, it was observed that the uncertainty associated to Nespresso demand does not modify the optimal networks according to each dimension, and that although there are some similarities between these networks, there is no optimal network, i.e., one network that provides the best performance in all dimensions of sustainability.

According to this conclusion, and with the multi-objective analyses elaborated, it is possible to recommend a set of networks that, although they do not proportionate the best performance in all indicators, provide good performances in all indicators. The choice of one of these networks depends exclusively on the hierarchisation of the dimensions, i.e., Nespresso's preference for a network with better economic, environmental or social performance, or for a network with intermediate levels in the indicators. Nevertheless, a network is suggested which although it is not optimal in terms of sustainability, performs well in the various indicators evaluated.

For future development, a more depth analysis of the additional fixed cost would be interesting, as although there are no changes in the configuration of the network, it causes a variation in the total cost of the network. Furthermore, knowing that all the values obtained in the environmental impact are directly related to the distances considered, the assumption made to determine the best location of each market influences the results obtained. Therefore, for a future study it would be interesting to analyse the location of each postal code individually and not to assume location close to followed postal codes. Moreover, since it has been assumed that several OFCs have the same value of social indicators, there may be a discrepancy in the results being considered, so for future development it is essential to study these values in detail in order to refine the indicator values as well as the results obtained.

In this work the reverse logistics, in particular the collection of coffee capsules and the recycling process, were not considered, despite the selected basis model. The not inclusion is due to the fact that it is not part of Nespresso's objective, but in future work, both reverse and forward logistics could be analysed in order to verify how the reverse logistics can affect, at the strategic and tactical level, the configuration of the networks.

In conclusion, this work is expected to be a useful tool for Nespresso in sustaining its decision and finding more sustainable alternatives.

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Appendix 1 – Demand Forecast Parameters

Table 24: Demand Forecast Parameters for each market

	CGRPO	CAGR	ADG
MarketA	-3%	-5.5%	2.55%
MarketB	-3%	21.5%	25.29%
MarketC	-3%	-2.4%	0.61%
MarketD	-3%	-2.2%	0.79%
MarketE	-3%	19.1%	22.83%
MarketF	-3%	-1.3%	1.76%
MarketG	-3%	5.2%	8.41%
MarketH	-3%	-6.8%	-3.87%
MarketI	-3%	0.0%	3.09%
MarketJ	-3%	-2.9%	0.07%
MarketK	-3%	7.7%	10.99%
MarketL	-3%	4.0%	7.24%
MarketM	-3%	-5.2%	-2.23%
MarketN	-3%	-3.1%	-0.13%
MarketO	-3%	2.3%	5.45%
MarketP	-3%	-4.1%	-1.14%
MarketQ	-3%	8.3%	11.60%
MarketR	-3%	1.6%	4.75%
MarketS	-3%	-2.5%	0.52%

Appendix 2 – Scenarios' ADG

Table 25: Annual Demand Growth (ADG) by markets in each scenario

	ADG (Baseline Scenario)	ADG (Scenario 2)	ADG (Scenario 3)	ADG (Scenario 4)	ADG (Scenario 5)
MarketA	2.55%	-2.80%	-2.29%	-2.29%	-2.80%
MarketB	25.29%	0.67%	0.54%	0.67%	0.54%
MarketC	0.61%	27.82%	22.76%	27.82%	22.76%
MarketD	0.79%	0.87%	0.71%	0.87%	0.71%
MarketE	22.83%	25.11%	20.55%	25.11%	20.55%
MarketF	1.76%	1.94%	1.59%	1.94%	1.59%
MarketG	8.41%	9.25%	7.57%	9.25%	7.57%
MarketH	-3.87%	-4.26%	-3.48%	-3.48%	-4.26%
MarketI	3.09%	3.40%	2.78%	3.40%	2.78%
MarketJ	0.07%	0.08%	0.07%	0.08%	0.07%
MarketK	10.99%	12.08%	9.89%	12.08%	9.89%
MarketL	7.24%	7.96%	6.51%	7.96%	6.51%
MarketM	-2.23%	-2.45%	-2.01%	-2.01%	-2.45%
MarketN	-0.13%	-0.15%	-0.12%	-0.12%	-0.15%
MarketO	5.45%	5.99%	4.90%	5.99%	4.90%
MarketP	-1.14%	-1.25%	-1.03%	-1.03%	-1.25%
MarketQ	11.60%	12.76%	10.44%	12.76%	10.44%
MarketR	4.75%	5.22%	4.27%	5.22%	4.27%
MarketS	0.52%	0.58%	0.47%	0.58%	0.47%

Appendix 3 – OFC – Markets Combinations

Table 26: Combination of OFC-Market allocations to the MarketN, MarketM and MarketJ and performance in the 3 sustainability indicators

	Market	*OFC7*	*OFC6*	*OFC3*	*OFC8*	*OFC3*	*OFC11*	*OFC12*	*Network Total Cost (M of MU)*	*Environmental Impact*	*Social Impact*
1st	MarketN	X							493.2 (+ 2.20%)	1782985 (- 8.95%)	16262 (+ 3.02%)
	MarketM			X							
	MarketJ						X				
2nd	MarketN	X							494.6 (+ 2.49%)	1651982 (- 15.64%)	16262 (+ 3.02%)
	MarketM			X							
	MarketJ							X			
3rd	MarketN	X							498.8 (+ 3.36%)	1706502 (- 12.86%)	16612 (+ 5.23%)
	MarketM				X						
	MarketJ						X				
4th	MarketN	X							500.2 (+ 3.64%)	1575499 (- 19.54%)	16612 (+ 5.23%)
	MarketM				X						
	MarketJ							X			
5th	MarketN	X							501.7 (+ 3.96%)	1771010 (- 9.56%)	17254 (+ 9.30%)
	MarketM					X					
	MarketJ						X				
6th	MarketN	X							503.2 (+ 4.27%)	1640006 (- 16.25%)	17254 (+ 9.30%)
	MarketM					X					
	MarketJ							X			
7th	MarketN		X						497.5 (+ 3.09%)	1667522 (- 14.85%)	16262 (+ 3.02%)
	MarketM			X							
	MarketJ						X				
8th	MarketN		X						499.0 (+ 3.40%)	1536518 (- 21.54%)	16262 (+ 3.02%)
	MarketM			X							
	MarketJ							X			
9th	MarketN		X						503.1 (+ 4.25%)	1591038 (- 18.75%)	16612 (+ 5.23%)
	MarketM				X						
	MarketJ						X				
10th	MarketN		X								

	MarketM		X				504.6 (+ 4.56%)	1460035 (- 25.44%)	16612 (+ 5.23%)
	MarketJ					X			
11th	MarketN	X					506.0 (+ 4.85%)	1655546 (- 15.46%)	17254 (+ 9.30%)
	MarketM			X					
	MarketJ				X				
12th	MarketN	X					507.5 (+ 5.16%)	1524542 (- 22.15%)	17254 (+ 9.30%)
	MarketM			X					
	MarketJ					X			

Appendix 4 – Computational Results

Table 27: Computational Results

Analyses	***# Total Variables***	***# Discrete Variables***	***# Total Constrains***	***GAP***	***Execution Time (seconds)***
Economic Network	61 680	7 939	64 800	0.00%	38.001
Environmental Network	61 680	7 939	64 800	0.00%	39.437
GDP Network	61 680	7 939	64 800	0.00%	41.843
Unemployment Rate Network	61 680	7 939	64 800	0.00%	45.484
Multi Objective (Economic vs Environmental Dimensions)	61 680	7 939	64 801	0.01%	318.204
Multi Objective (Economic vs Social Dimensions)	61 680	7 939	64 801	0.01%	425.543
Multi Objective (Economic, Environmental and Social Dimensions)	61 683	7 939	64 803	0.01%	1009.875
Scenarios	308 288	39 619	323 964	0.00%	659.516