Optimal Sustainable Distribution Network: The case of Nespresso

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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. This project explores this need and focuses on the optimal design and planning of the Nespresso distribution network. 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. Thus, it was studied which OFCs (Order Fulfilment Centres) should be used and which markets they should supply so that the Nespresso distribution network is sustainable. With the model elaborated and the data collected it was observed that there is no optimal network in the three dimensions of sustainability, but that it is possible to obtain a distribution network that performs well in all dimensions. Compared to the current distribution network, the recommended network represents an improvement on an economic and environmental level, and a slight loss in the social dimension.

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

1. Introduction

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 the one hand, this growth is due to the improvement in both the equipment/machines available and the quality, felt by consumers, that coffee in capsules provides. 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 inside the 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 current 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. 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.

Taking this objective in consideration, the remaining paper is divided into 5 more sections. Section 2 presents the case study and section 3 present the literature review on the concepts most relevant to the problem under study. In section 4 the mathematical formulation of the model is presented, and in section 5 an analysis of the results and recommendation of the distribution network are prepared. Finally, section 6 prepares the paper’s conclusions.

2. Case-Study

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). On 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).

2.1. Nespresso Supply Chain

Nespresso's supply chain includes different entities, from the coffee producers to the end consumers, and therefore different relationships between entities. Starting with the suppliers, Nespresso works with over 70 000 coffee suppliers around the world and there is a direct relationship between them. 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. The products are transported to the International Distribution Centre located in Avenches. 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). In 2018, there were approximately 130 OFCs covering 50 markets worldwide, which is equivalent to 60/70 countries (Moderna, 2018).

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).

2.2. 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. Nespresso has felt the impact of e-commerce growth since it has led to an increase in costs proportionate to profits. This leads to a challenge in Nespresso that is to optimise their Supply Chain.

2.3. Nespresso Supply Chain Challenge

Nespresso currently has a decentralised OFC network, as it has at least one OFC in most countries. This offers faster delivery to consumers, but at the same time increases existing costs. 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.

As 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, it has been decided that only a few countries distributed over a given area of the world coffee market will be analysed, and these are representative of the highest volume of Nespresso demand. This work is then to be developed exploring sustainable supply chain objectives: economic, environmental and social.

2.4. 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. 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. 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.

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. Moreover, monthly demand forecasts for the next 5 years will be taken into account.

3. Literature Review

3.1. Supply Chain

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. 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. 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).

R.K. Oliver and M.D. Weber 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). 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). 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).

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 are being addressed in establishing a sustainable supply chain, and which types of logistics 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. The strategic decisions 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 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 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 and understand how they intend to promote the interconnection between these three spheres in the future vision of the company. 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), since many business decisions were analysed according to revenue and costs.

The environmental dimension aims at identifying costs and revenues related to the environment, investment in environmental protection and the use of new indicators to assess environmental performance (John Elkington, 1999). Concerning this dimension, Life Cycle Assessment (LCA) is considered the most reliable method (Mota, Gomes, Carvalho, & Barbosa-Povoa, 2015).

The social level is sometimes neglected by companies, but it is a very important factor in determining the success of sustainability in the company (John Elkington, 1999). This dimension corresponds to offering equitable opportunities, encouraging diversity and ensuring quality of life (John Elkington, 1999).

These three pillars 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.

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.

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). Reverse Logistics includes the reverse flow activities and 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).

In addition to this logistics, it is also considered the Closed Loop Supply Chain (CLSC) which consists of the integration of Forward and Reverse Logistics. So, 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).

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. However, this 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). Therefore, the model developed by Mota et al., (2018) was chosen to be extended to the problem under study, since it encompasses the three dimensions of sustainability and allows the use of stochastic parameters.

4. Model

Three sets of entities are considered. The first corresponding to the factories, the second corresponding to the OFCs and finally, the customers or markets that need to be satisfied. Figure 1 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.

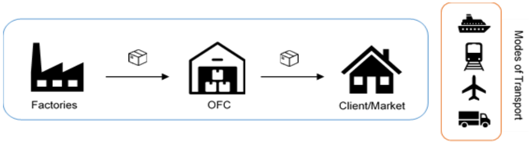

Figure 1: Representative scheme of the entities present in a generic supply chain

Through this structure of the network, it is intended to create a model that includes sustainability, based on existing entities, products and modes of transport, and that has as its objective the design of the supply chain. At the economic level it is intended to minimize the total costs, at the environmental level it is intended to minimize the environmental impact caused by the transport of products between entities, and finally, at the social level it is intended to maximize the social impact generated according to two different indicators: GDP and Unemployment rate. In view of these objectives and considering the case study the aim is to define which OFCs should be used, which markets or customers they supply.

4.1. Mathematical Formulation

In Table 1 is presented all the notation required for the model, including the sets, subsets, parameters and decision-variables considered.

Table 1: Model Notation

Sets	
$i,io,id\ \epsilon\ I$	Entities
$m\ \epsilon\ M$	Products
$a\ \epsilon\ A$	Modes of Transport
$t\ \epsilon\ T$	Time periods
$mp\ \epsilon\ Midpoint$	Environmental Midpoints Categories
$sc\ \epsilon\ SC$	Scenarios
Subsets	
$i\ \epsilon\ I_f$	Factories
$i\ \epsilon\ I_w$	OFC
$i\ \epsilon\ I_c$	Customers
$i\ \epsilon\ I_{air}$	Airports
$i\ \epsilon\ I_{train}$	Train Stations
$i\ \epsilon\ I_{port}$	Seaports
$io,id\ \epsilon\ EntEnt$	Possible flows between entities
$a\ \epsilon\ A_{air}$	Plane
$a\ \epsilon\ A_{train}$	Train
$a\ \epsilon\ A_{boat}$	Boat
$a\ \epsilon\ A_{truck}$	Truck
$m,i\ \epsilon\ ProdE$	Allowed product-entity relations
$m,i,io\ \epsilon\ ProdF$	Allowed flows of products between entities
$a,i,io\ \epsilon\ Net$	Allowed transport modes between entities
$a,m,i,io\ \epsilon\ NetP$	All allowed network
Parameters	
$fixedcost_{I,t}$	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 $\in M$
$vartransp_{a,i,io}$	Cost of transport per product m and per km, between entities i and io, using the mode of transport a, , $(i, io) \in I,\ a \in A$
$pickingcost_{i,io,m}$	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, $i \in (I_w \cup I_f),\ m \in M$
$captransp_a$	Maximum contracted capacity of the mode of transport a, $a \in A$
$pTranspCap_a$	Capacity of the transport mode a, $a \in A$
$pCapmin_a$	Minimum cargo to be transported using transport mode a, $a \in A$
$productweight_m$	Weight of product m, $m \in M$
$demand_{m,i,t,sc}$	Demand of client/market for product m in time period *t* according to the scenario *sc*, $i \in I_c , m \in M , t \in T,\ sc \in SC$

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, $i \in I_w$
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, $mp \in Midpoint$
probsc$_{sc}$	Probability of each scenario *sc* occurring, $sc \in SC$
pBOMTsame$_{m,mm}$	Relation between products m entering and mm products 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, $(m,mm) \in M$
Decision-Variables	
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 $sc,\ \ i \in (I_w \cup I_f), m \in M,\ \ t \in T, sc\ \in\ SC$;
Y$_i$ ϵ {0,1}	1, if the entity $i \in$ I is used; 0 otherwise;
Z$_{m,a,io,id,t,sc}$ ϵ {0,1}	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*, $, m \in M, a\ \in A, (io,id) \in I,\ t \in T, sc\ \in\ SC$; 0 otherwise;
Auxiliary Variables	
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

The restrictions associated to the problem and the objective functions considered are presented below:

$$\sum_{\substack{io:(m,io,id)\in ProdF_{INCFP}\\ a:(a,m,io,id)\in NetP}} X_{m,a,io,id,t,sc} = demand_{id,m,t,sc}\,, \quad m \in M, id \in\ I_c\,, t\ \in T, sc\ \in SC \tag{1}$$

$$production_{m,i,t,sc}\ + S_{m,i,t-1,sc} = \sum_{\substack{mm,id:\,(mm,i,id)\in ProdF_{OUTFFP}\\ a:\,(a,mm,i,id)\in NetP}} pBOMFsame_{m,mm} * X_{m,a,i,id,t,sc} + S_{m,i,t,sc}\,, \qquad m \in M, i \in I_f, t \in T, sc\ \in SC \tag{2}$$

$$\sum_{\substack{mm,io:(mm,io,i)\in ProdF_{INWFP}\\ a:(a,mm,io,i)\in NetP}} pBOMTsame_{m,mm} \times X_{mm,a,io,i,t,sc} + S_{m,i,t-1,sc} = \sum_{\substack{mm,id:(mm,i,id)\in ProdF_{OUTWFP}\\ a:(a,mm,i,id)\in NetP}} pBOMTsame_{m,mm} \times\ X_{m,a,i,id,t,sc} + S_{m,i,t,sc}\,, m \in M, i \in I_w, t\ \in T, sc\ \in SC \tag{3}$$

$$\sum_{\substack{mm,io:(mm,io,i)\in ProdF_{INTRAIN}\\ a:(a,mm,io,i)\in NetP}} X_{mm,a,io,i,t,sc} \times\ pBOMTsame_{m,mm} = \sum_{\substack{mm,io:(mm,i,id)\in ProdF_{OUTTRAIN}\\ a:(a,mm,i,id)\in NetP}} X_{mm,a,i,id,t,sc} \times pBOMTsame_{m,mm}\,, \qquad m \in M, i\ \in I_{train}, t\ \in T\,, sc\ \in SC \tag{4}$$

$$\sum_{\substack{mm,io:(mm,io,i)\in ProdF_{INAIR}\\ a:(a,mm,io,i)\in NetP}} X_{mm,a,io,i,t,sc} \times\ pBOMTsame_{m,mm} = \sum_{\substack{mm,io:(mm,i,id)\in ProdF_{OUTAIR}\\ a:(a,mm,i,id)\in NetP}} X_{mm,a,i,id,t,sc} \times pBOMTsame_{m,mm}\,, \qquad m \in M\,, i\ \in I_{air}, t\ \in T, sc\ \in SC \tag{5}$$

$$\sum_{\substack{mm,io:(mm,io,i)\in ProdF_{INPORT}\\ a:(a,mm,io,i)\in NetP}} X_{mm,a,io,i,t,sc} \times\ pBOMTsame_{m,mm} = \sum_{\substack{mm,io:(mm,i,id)\in ProdF_{OUTPORT}\\ a:(a,mm,i,id)\in NetP}} X_{mm,a,i,id,t,sc} \times pBOMTsame_{m,mm}\,, \qquad m \in M\,, i\ \in I_{port}, t\ \in T, sc\ \in SC \tag{6}$$

$$\sum_{a,m,io:(a,m,io,i)\in NetP} X_{m,a,io,i,t,sc} \leq\ flowmax_i * y_i\,, i\ \in I_w\,, t \in T, sc\ \in SC \tag{7}$$

$$\sum_{a,m,i:(a,m,io,i)\in NetP} X_{m,a,io,i,t,sc} \leq\ flowmax_{io} * y_{i0}\,, io \in\ I_w, t\ \in T, sc\ \in SC \tag{8}$$

$$\sum_{\substack{a,m,i:(a,m,io,i)\in NetP\\ i\in I_c}} X_{m,a,io,i,t,sc} \times\ hourperorder_i \leq\ horamax_{io} * y_{i0}\,, io \in I_w, t \in T, sc\ \in SC \tag{9}$$

$$S_{m,i,t,sc} \leq stockmax_i * y_i\,, i\ \in\ I_w\,, m \in M\,, t\ \in T, sc\ \in SC \tag{10}$$

$$S_{m,i,t,sc} \geq stockmin_i * y_{i,}\ i \in I_w, m \in M, t \in T, sc \in SC \tag{11}$$

$$\sum_{m:(a,m,io,id) \in NetP} X_{m,a,io,id,t,sc} \leq captransp_a, \quad (a,io,id) \in Net, t \in T, sc \in SC \tag{12}$$

$$\sum_{\substack{a,io:(a,m,io,i) \in NetP \\ io \in I \backslash I_{train}}} X_{mm,a,io,i,t,sc} = \sum_{\substack{a,id:(a,m,i,id) \in NetP \\ id \in I_{train}}} X_{mm,a,i,id,t,sc}, m \in M, i \in I_{train}, t \in T, sc \in SC \tag{13}$$

$$\sum_{\substack{a,io:(a,m,io,i) \in NetP \\ io \in I \backslash I_{air}}} X_{mm,a,io,i,t,sc} = \sum_{\substack{a,id:(a,m,i,id) \in NetP \\ id \in I_{air}}} X_{mm,a,i,id,t,sc}, m \in M, i \in I_{air}, t \in T, sc \in SC \tag{14}$$

$$\sum_{\substack{a,io:(a,m,io,i) \in NetP \\ io \in I \backslash I_{port}}} X_{mm,a,io,i,t,sc} = \sum_{\substack{a,id:(a,m,i,id) \in NetP \\ id \in I_{port}}} X_{mm,a,i,id,t,sc}, m \in M, i \in I_{port}, t \in T, sc \in SC \tag{15}$$

$$Z_{m,a,io,id,t,sc} \times BigM \geq X_{m,a,io,id,t,sc}, (a,m,io,id) \in NetP, t \in T, sc \in SC \tag{16}$$

$$\sum_{io \in I} Z_{m,a,io,id,t,sc} = 1, (a,m,io,id,sc) \in NetP, id \in I_c, t \in T, sc \in SC \tag{17}$$

$$workers_{io,id,t,sc} = \sum_{m \in M} \sum_{a \in A} \frac{X_{m,a,io,id,t,sc}}{workerproductivity_m}, io \in I_w, id \in I_c, t \in T, sc \in SC \tag{18}$$

$$workers_{io,sc} = \sum_{id \in I} \sum_{t \in T} \frac{workers_{io,id,t,sc}}{12}, io \in I_w, sc \in SC \tag{19}$$

$$vTranspImpact_{a,mp,sc} = \sum_{m,io,id:(a,m,io,id) \in NetP} \sum_{t \in T} TranspImpact_{a,mp} \times Productweight_m \times Distance_{io,id} \times X_{m,a,io,id,t,sc}, a \in A, mp \in Midpoint, sc \in SC \tag{20}$$

$$\begin{aligned} Min\ TC = \sum_{sc \in SC} probsc_{sc} \sum_{t \in T} \Bigg(& \sum_{i \in I_w} fixedcost_{i,t} * y_i \\ & + \sum_{(m,i) \in ProdEnt} stockcost_{i,m} \times S_{m,i,t,sc} \\ & + \sum_{(a,m,io,id) \in NetP} pickingcost_{io,id,m} \times X_{m,a,io,id,t,sc} \\ & + \sum_{(a,m,io,id) \in NetP} handlingcost_{io,m} \times X_{m,a,io,id,t,sc} \\ & + \sum_{(a,m,io,id) \in NetP} additionalfc_{io,id} \times Z_{m,a,io,id,t,sc} \\ & + \sum_{(a,m,io,id) \in NetP} vartransp_{io,id} \times X_{m,a,io,id,t,sc} \times distance_{io,id} \Bigg) \end{aligned} \tag{21}$$

$$\text{Min } vEnvImpact = \sum_{sc \in SC} probsc_{sc} \times \sum_{\substack{a \in A \\ mp \in Midpoint}} NormFactor_{mp} \times vTranspImpact_{a,mp,sc} \tag{22}$$

$$Max\ vGDPInd = \sum_{sc \in SC} probsc_{sc} \times \sum_{i \in I_w} \frac{1}{GDPInd_i} \times vworkers_{i,sc} \tag{23}$$

$$Max\ vUnemploymenyRateInd = \sum_{sc \in SC} probsc_{sc} \times \sum_{i \in I_w} UnemploymentRateInd_i \times vworkers_{i,sc} \tag{24}$$

The equation (1) 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. The equations (2), (3), (4), (5) and (6) correspond to the material balance refer, respectively, to the balance in factories, OFCs, train stations, airports, and seaports. Equations (7), (8) and (9) restrict the flow between each pair of entities if they are open. This limitation in the flow can be evaluated in two different parameters, referring to the maximum order quantity (equations (7) and (8)), and other referring to the number of hours available in the OFC for the products preparation (equation (9)).

Equations (10) and (11) 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 ($stockmin_i$).

For the products transportation, equation (12) 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 (13),(14) and (15) 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.

Equation (16) 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 (17) establishes that each market can only be satisfied by one OFC.

Equations (18) 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 (19) aims to calculate the average monthly number of workers required in OFC *io* considering the markets *id* it supplies.

For the environmental dimension, equation (20) defines the total impact caused by the mode of transport *a* at each midpoint *mp* and in each scenario considered ($vTranspImpact_{a,mp,sc}$).

Regarding the objective functions, in the economic dimensions (equation (21)) it is intended to minimize the total costs (TC) in the forward supply chain. For that purpose, 6 types of costs are considered: fixed cost, storage cost, picking cost, handling cost, additional fixed cost and transportation cost. The equation (22) corresponds to the objective function according the environmental dimension and it aims to minimize the environmental impacts caused by the transport of products. In the social dimension, there are two objective functions, being that equation (23) 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. According to Unemployment Rate (UR) Indicator (equation (24)), it aims to use the OFCs and potentiate the products' volume in them, in locations where the UR is higher.

5. Case Study Results and Recommendations

5.1. Economic Network

According to the economic dimension, 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 6 different allocations from the current network, corresponding to the supply of the MarketM, MarketR, MarketS, MarketI, MarketJ and MarketN. These different allocations allow to a reduction of 42.5 million MU. Although the additional fixed cost is not pre-determined, through a sensitivity analysis it is possible to verify that there is no change in the economic network to values close to those considered, which makes this network robust.

Table 2: Economic Network

OFC	***Market***		
OFC3	MarketQ	MarketM	MarketB
OFC4	MarketO		
OFC7	MarketN		
OFC9	MarketL		
OFC10	MarketK	MarketS	
OFC11	MarketJ		
OFC13	MarketH		
OFC14	MarketG		
OFC15	MarketF		
OFC16	MarketE		
OFC17	MarketD	MarketP	
OFC18	MarketI	MarketC	MarketR
OFC19	MarketA		

5.2. Environmental Network

When considering the objective as the minimisation of the environment impact of the Nespresso distribution network it was observed that the use of the train was maximised as the train is the mode of transport with the lowest impact per Km travelled and per Kg transported. So, 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, according to the possible allocations between OFCs and markets. According to this objective, only open 10 OFCs. Compared to the economic network, only 8 OFC-Market allocations are the same in the environmental network and correspond to the supply of the MarketL, MarketG, MarketL, MarketD, MarketP, MarketC, MarketI and MarketA. 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). The MarketR will be supplied by the OFC2, the MarketM by the OFC8, the MarketJ by the OFC12 and the MarketN by the OFC19. Due to the low number of equal OFCs-Markets allocations, there will be significant differences in the performance of each of these networks. Although the environmental network has the lowest impact for the environment, 35.52% less environmental impact than the economic network, it would impose the highest cost, being 33% higher than the total cost in the economic network and would exceed the current cost forecast from 2019 to 2023 if the network remains the same.

5.3. Social Network

By combining all the restrictions and the objective function of the GDP indicator, it is obtained a network with 12 OFCs open, resulting in 4 different clusters from those of the economic dimension. OFC2 prepares orders for 3 markets (MarketR, MarketI and MarketC), OFC4 for 2 markets (MarketO and MarketP), OFC10 for 4 markets (MarketK, MarketS, MarketQ and MarketB) and OFC17 for 2 markets (MarketD and MarketH).

As the GDP indicator values of OFC5, OFC6 and OFC7 are the same and these can supply the same market, he 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.

The same choice will happen on the network according to the Unemployment Rate indicator.

According to the UR 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. 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. For the MarketL, MarketG, MarketF and MarketA, the OFCs that supply them are the same as in the economic network.

In terms of costs, these two social networks represent a higher economic effort for Nespresso compared with the economic network. While the network according to the GDP indicator would increase by 3.91%, the network according to UR indicator would imply an increase of 5.88% in terms of costs. Regarding the performance in the social indicators, the GDP network shows the best performance in that indicator, and the second best performance in the other social indicator, and the UR network has the best performance in that indicator and the worst performance in the GDP indicator.

5.4. Scenario Analysis

In all the analyses elaborated 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 (Figure 2). Through the analysis it is verified that there are no changes in the networks.

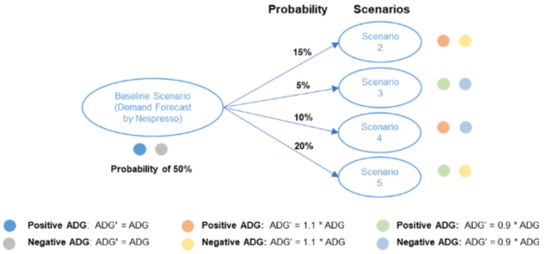

Figure 2: Scenarios (ADG: Annual Demand Growth)

5.5. Sustainable Network

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, a multi-objective analyses is developed to find the best combinations of networks that meet more than one dimension. For the analysis of the social dimension, only the UR indicator will be considered.

5.5.1. Economic vs Environmental Dimension

According to the Figure 4, 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.

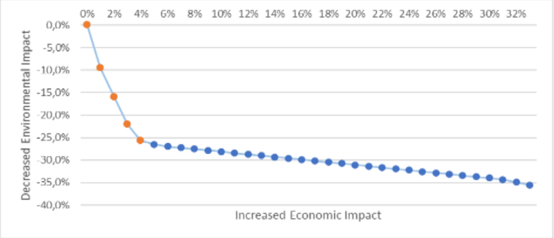

Figure 4: Multi-Objective Analysis: Economic and Environmental Dimensions

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. 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). In the fourth network, compared to the previous network, another change of allocation happens, which corresponds to the supply of the MarketN by OFC6. 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.

5.5.2. Economic vs Social Dimension

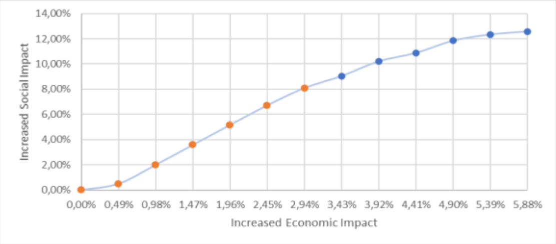

Figure 3: Multi-Objective Analysis: Economic and Social Dimensions (Unemployment Rate Indicator)

Figure 3 shows 13 networks, which include the economic 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. Given the behaviour of the multi-objective curve, only the networks corresponding to the increases from 0.5% to 3% (orange circles) will be analysed in more detail, as they show a higher growth in the social indicator compared to the others. In the network corresponding to the increase up to 0.5% 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. In the third network of the value concerning the increase of up to 1% in the total cost of the network, there is 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. In the networks corresponding to the increase in total cost of 1.5%, 2.0% and 2.5%, 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. When an increase of up to 3% 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 market of MarketC. In addition, OFC10 supplies MarketQ and MarketB.

5.5.3. Economic vs Environmental vs Social Dimension

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 5. Of the 54 networks 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.

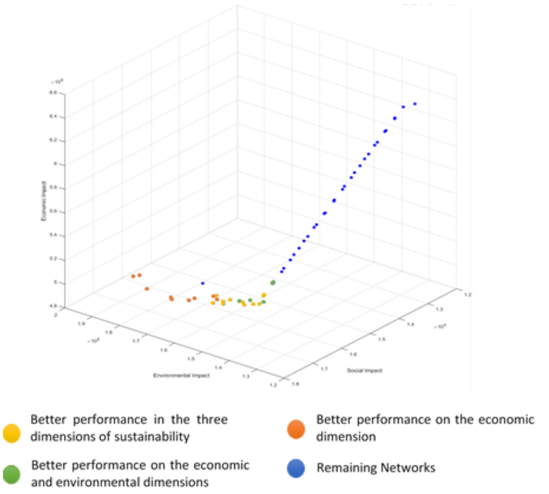

Figure 5: Multi-Objective Analysis: Economic, Environmental and Social Dimensions

5.6. Recommended Network

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, in the sustainable network these allocations must be present.

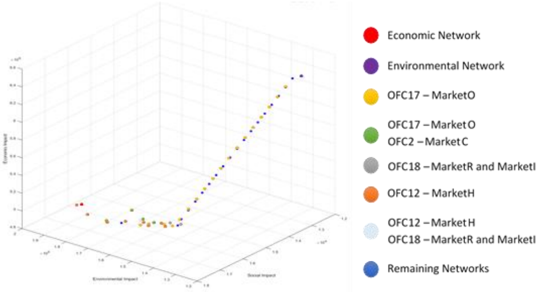

Figure 6: Multi-Objective Analysis of the Three Dimensions of Sustainability and Networks Allocations

Regarding the MarketO and MarketC, although the allocations differ according to the indicators evaluated, none of these changes is verified in the areas analysed in the two-dimensional multi-objective graphs. Moreover, 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 6). Consequently, it is defined that orders from the MarketO will be prepared by OFC4 and orders form 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 6). 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. So MarketH should be supply by OFC13.

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 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. Thus, the sustainable network will include these 5 OFC-Market allocations. Furthermore, with exception of the MarketE, the allocation of the remaining 4 markets is common both in the networks with best economic and environmental impact, 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.

The MarketR and MarketI allocations to the OFC2 result in an improvement in the social and environmental indicator, with a small increase in cost. Additionally, 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 6). So, these allocations are present in the sustainable network.

For the MarketN, MarketM and MarketJ according to different networks and analyses, different OFCs can be allocated to these markets. Giving greater preference to environmental performance and considering the ratio between incremental cost and improved environmental performance, the MarketM should be supplied OFC3, the MarketJ by OFC12, and the MarketN by OFC6. 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.

Compared to the current Nespresso network, the suggested network keeps 12 OFC-Market allocations equal (Table 3), differentiating in allocations to the MarketK, MarketQ, MarketB, MarketE, MarketN, MarketJ and MarketM. This recommended network allows savings of 26.1 million MU, and in environmental indicator, it represents a decrease of 2.69%, and according to Unemployment Rate indicator, it represents a loss of 1.37%.

Table 3: 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		

6. Conclusion

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.

Given the variety of Nespresso products and the variety of customers, the complexity inherent to this work is quite considerable. Consequently, it was necessary to adopt strategies that allow a lower computational impact, namely the aggregation of customers by country and the consideration of only one type of product.

Considering all the 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. According to this conclusion, and with the multi-objective analyses elaborated, it is possible to recommend a set of networks that provide good performances in all indicators. The choice of one of these networks depends exclusively on the Nespresso's preference, for a network with better economic, environmental or social performance. Nevertheless, a network is suggested which performs well in the various indicators evaluated.

For future development, a more depth analysis of the additional fixed cost would be interesting, as it causes a variation in the total cost of the network. Additionally, it would be interesting to analyse the location of each postal code individually and not to assume location close to followed postal codes, and to analyse both reverse and forward logistics.

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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