Barriers Analysis for Supply Chain Collaboration

in Industrial Symbiosis Networks: a case in the olive oil industry

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DECLARATION

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

Declaração

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

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To everyone, best wishes!

Abstract

In Portugal, the olive agro-industrial sector has tremendous socio-economic relevance and key implications on global employment and revenue. However, the impacts of increasing olive oil production and consumption on the environment are considerable, mainly due to the demand of large inputs of resources and the large amounts of by-products generated. In the vast majority of cases these by-products are unexploited, although they could be converted into a zero-waste supply chain, implementing waste-to-energy solutions throughout a circular economy (CE) perspective.

Considering the latter, the research problem in this project concerns the conditions for developing stable industrial symbiosis (IS) relationships between involved entities, guaranteeing that the IS is beneficial for every party. Each player in the industrial symbiosis can benefit from this relationship in multiple aspects, for instance: more efficient use of resources, reduce waste, increase profits, share knowledge, thus reducing the firm's vulnerability in environments characterized by diverse levels of uncertainty. Earlier studies have presented drivers that support the introduction of new IS relationships in order to support CE, as well as common barriers that hinder its establishment.

Hence, the olive oil industry is characterized, alongside a brief description regarding the olive oil management integrated supply chain. Then, a literature review on the problem's most relevant concepts is performed to provide a theoretical framework for the future work explored in the following sections. An empirical illustration of potential barriers towards the development of IS relationships is presented, including the several ones: Trust, Beliefs, Risk and Uncertainty, Economic and Operational, Skills and Technology, Governmental, Complexity and Responsibility. Then, methods to overcome the barriers and encourage a better implementation of CE across the supply chain were suggested.

Keywords: Olive oil, Supply Chain, Sustainability, By-products, Industrial Symbiosis, Barriers.

Resumo

Em Portugal, o sector agro-industrial, especificamente o do azeite, tem uma enorme relevância socioeconómica e implicações a nível das receitas mundiais e de empregabilidade. No entanto, os impactos do aumento dos padrões de produção e consumo de azeite no ambiente são consideráveis, principalmente devido à enorme procura de recursos e às quantidades de subprodutos gerados. Na grande maioria dos casos, estes subprodutos não são subutilizados, embora haja a oportunidade de converter a cadeia de abastecimento para desperdício nulo, através da economia circular (EC).

Neste contexto, o problema introduzido neste projeto diz respeito ao desenvolvimento de relações de simbiose industrial (SI) estáveis, entre entidades envolvidas e de modo a garantir que a SI é benéfica para todas as partes. Cada interveniente pode beneficiar desta relação em vários aspetos, como por exemplo: uso mais eficiente de recursos, redução de desperdícios, aumento de lucros, partilha de conhecimento, reduzindo assim a vulnerabilidade da empresa em ambientes caracterizados por diversos fatores e níveis de incerteza. Estudos anteriores apresentaram motivações que apoiam a introdução de novas relações de SI para apoiar a CE, bem como barreiras que dificultam o seu estabelecimento.

Primeiramente, o problema em estudo é apresentado e sua motivação. Em seguida, caracteriza-se a indústria do azeite, em conjunto com uma breve descrição da gestão integrada da cadeia de abastecimento do azeite. Em seguida, uma revisão da literatura sobre os conceitos mais relevantes do problema é realizada para fornecer um enquadramento teórico para o futuro trabalho explorado nas seções seguintes. Uma ilustração empírica de potenciais barreiras para o desenvolvimento de relações de SI ao nível da cadeia de abastecimento, incluindo as seguintes: Confiança, Crenças, Risco e Incerteza, Económico e Operacional, Habilidades e Tecnologia, Governamental, Complexidade e Responsabilidade. Seguidamente, métodos para superá-las e incentivar uma melhor implementação de EC em toda a cadeia foram sugeridos.

Palavras-chave: Azeite, Cadeia de Abastecimento, Sustentabilidade, Subprodutos, Simbiose Industrial, Barreiras.

Contents

List of Figures

List of Tables

Acronyms

CE: Circular Economy

CLSC: Closed Loop Supply Chain

CSSC: Circular Symbiotic Supply Chain

EU: European Union

FL: Forward Logistics

LCA: Life Cycle Assessment

MILP: Mixed Integer Linear Programming

NPV: Net Present Value

OMW: Olive Mill Wastewaters

OP: Olive Pomace

RL: Reverse Logistics

SC: Supply Chain

SCM: Supply Chain Management

SSC: Sustainable Supply Chain

SSCM: Supply Chain Symbiotic Models

UK: United Kingdom

1 Introduction

1.1 Contextualization

The food and beverage industry is one of the most important sectors of the European Union (EU) economy, in terms of employment, turnover, and value-added. The EU is a net exporter of food and beverages with a positive trade balance of 30.1 billion euros, generating 60% of the total biomass demand. However, it is estimated that around 88 megatons of food are wasted annually, which represents around 20% of all food produced, and the associated costs are estimated at 143 billion euros (Valin et al., 2015). In the last ten years, the current economic model, which is based on the so-called “take- make- dispose” paradigm, has become more popular (Esposito et al., 2020). The depletion of resources and environmental degradation were driven by globalization and consumerism. This is an effect of exponential population growth, higher living standards, and increasing popularity of certain diets, therefore leading to higher demand for certain products. The agri-food sector (AFS) in particular has been suffering from problems, such as food shortage and waste accumulation across the supply chain. In fact, projections for 2050 indicate the emergence of growing scarcities of agricultural land (Esposito et al., 2020). Based on FAO statistics, between 2005 and 2015, natural catastrophic events such as droughts and floods cost the agri-food sector approximately $96 billion in loss. As shown in Figure 1, stressing factors are directly threatening the future availability of natural resources.

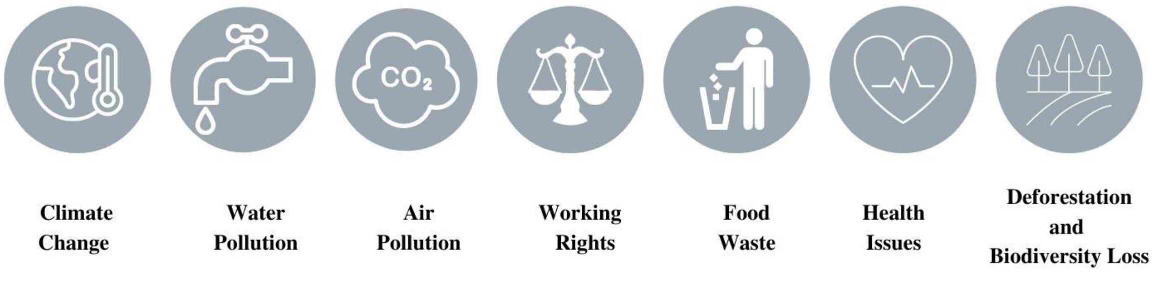


Figure 1- Highlighted agri-food industry stress factors

To guarantee a more resilient “tomorrow”, stakeholders must be aware of upcoming trends and possible disruption into their business strategy (McKinsey, 2021). According to AgFunder (2020), the amount of money invested into agri-food technology indicated a sixfold increase starting in 2012: from $3 billion to nearly $18 billion. New technologies should be enforced not just for innovation purposes, but also to enhance and address important customer needs and redesign supply chains (Agfunder, 2020). These innovative technologies can be segmented into upstream, relevant for cultivation and food handling, and downstream, for customer conveyance and distribution. The upstream tech patterns are the ones confronting the fundamental rural difficulties of upcoming years. They incorporate alternative cultivating frameworks, precision techniques, biotechnology, and others, allowing to decrease information gaps, increase information sharing, and increase production yields to very positive levels (McKinsey, 2020).

Accordingly, with the study: *"Alentejo: A Liderança a Olivicultura Moderna Internacional"* (2019), a few years ago, companies playing important roles in global food chains that have been producing foodstuff, started caring more about food quality and the risks associated with their activity, since the consumer is becoming more aware of these issues. Environmental responsibility, fair trade, and consumers' health are some of the current concerns. Consumers are also more curious about the process behind the product they buy, from cradle to grave. Today, there is a chance for everyone to form properly informed decisions.

Olive oil, as the name indicates, is the final product of oil extraction from olives and has become a very important product for the Portuguese economy. For the EU, olive oil is considered one of the principal products in the agricultural business sector, more specifically, the southern Member States (Mediterranean area), which accounts for 76% of world's olive oil production. The most relevant European olive oil producer is Spain, followed by Italy and Greece and, in fourth place, Portugal (GPP, 2017). In recent years, Portugal has suffered a sudden evolution in the industrial agri-food field due to the increasing tendency of olive oil consumption, both in the domestic market exportation countries, also known as olive oil "new consumers": USA (38%); Brazil (6%); Australia (3%); Canada (5%); Japan (7%) and China (4%) (GPP, 2017). Due to technology investments, it was possible to increase production levels, expand the areas occupied by the olive grove and increase to new maximum efficiency production yields, consolidating in European countries, even more, the reference of largest producers.

1.1.1 Sustainable Development and Circular Economy

The Food and Agriculture Organization (FAO) (2016) reports estimated that as much as 50% of the produced food is either lost or wasted before and after reaching the consumer, accounting for over 1.3 billion tons per year of food globally produced for human consumption. This situation obviously represents a major environmental, economic and social problem. For this reason, organizations such as the FAO and the Ellen McArthur Foundation (EMF) have brought more attention from optimizing production processes to responsible consumption, pushing the interest on the Circular Economy (CE) concept worldwide. In 2015, the Ellen McArthur Foundation together with McKinsey estimated that a CE approach could increase resource productivity by 3% by 2030, generating cost savings of around 600 billion euros a year and 1.8 trillion euros more in other economic benefits (McKinsey, 2017). If the quantity of unnecessary food loss is reduced globally through an enhanced waste management, positive impacts will be accomplished, such as reduced greenhouse gas emissions and a decrease over exploitation of land and water resources, but also on supplier profits and consumer wellbeing (Esposito et al., 2020).

The CE approach has revolutionized the way agriculture and industry are involved with each other. Several stakeholders changed their mindset, particularly in cases where the continuity and prosperity of an industry is so important to the economic development of the country. From a typical supply chain that was designed to act as a 'take-make-waste' linear model, where business continuity was supported on productive manpower and efficient operations, instead of being concerned with environmental or social impacts (EMF, 2015). The desired result is to have stakeholders with a more involved attitude in matters that focus on maintaining balance between producing a good and ensuring its continuity. Despite the supply chains' inherent sustainability risks, few organizations are aware of their sustainability issues, and the ones that are, rarely trigger collaborations with their suppliers in order to mitigate the risks. And, when businesses try to persuade their suppliers, they are most likely to face challenges ahead (McKinsey, 2016).

Supply Chains can be previously designed as a regenerative system, aiming to consciously dissociate consumption growth from finite resources, and changing the focus from a labor productivity to resource productivity. The quantification of food waste is tremendously difficult due to the fact that it occurs throughout the entire food supply chain: during manufacturing, transformation, retail distribution, warehouses, restaurants, establishments providing prepared foodstuffs. The majority of players do not have interconnected systems information that would enable an easier waste enumeration (Eriksson et al., 2018).

1.1.2 The olive Oil industry and Market

The olive oil industry faces constant demand, nevertheless supply does not behave the same way, suffering from instability. This challenge can influence the industry's demand-supply balance, and thus its pricing and investment dynamics. The value chain distribution income between the different players is affected. Europe is regularly positioned as one united market and often characterized as less entrepreneurial with more risk-averse profile and less sophisticated investors. As a result of emerging technologies that have the potential to reshape the agriculture and industrial sector, the agri-food industry is being increasingly eyed by entrepreneurs and investors. A SWOT analysis was performed in order to understand the olive oil industry's strengths, weaknesses, opportunities, and threats (Figure 2).

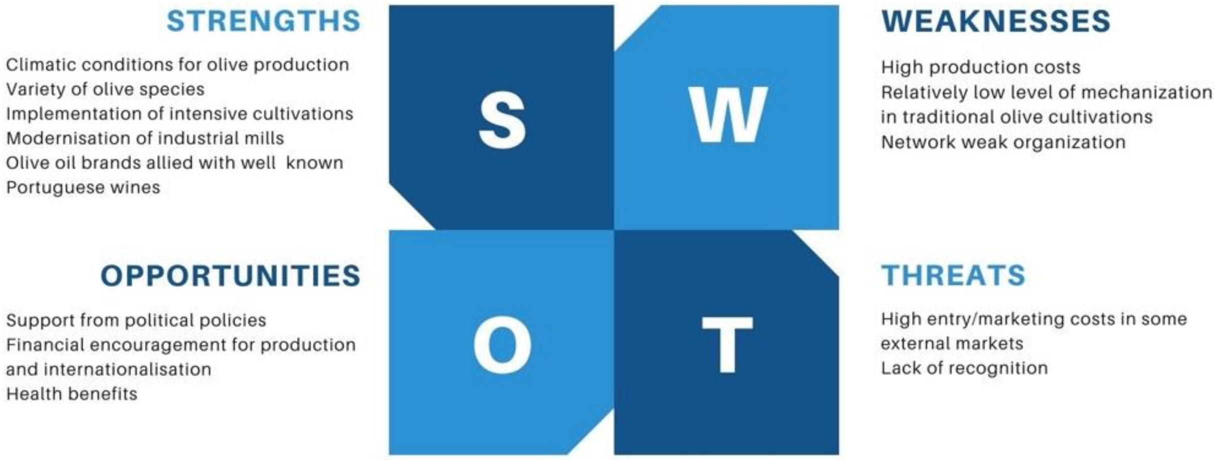


Figure 2- Olive Oil industry SWOT analysis (adapted from GPP, 2017)

Sustainable growth and balanced territorial development are necessary to achieve the European Commission's job positions growth and investment target. Working conditions in agriculture and forestry are constantly evolving and social conditions in agriculture deserve proper attention (EC, 2018). The olive Oil industry is in a phase of profound economic, demographic and institutional adjustments.

Ever since the beginning of times when olive oil began to be produced until this day, Europe remains the unquestionable olive oil main distributor, counting with a market share of about 70%, with more than 42% of the total number of persons employed in this business (Vilar, 2019). In each olive crop year, which happens once in a year, on average, demand for the workforce can be approximately 7 million working days which amounts to nearly 32 000 full time workers (considering that each shift is 8 hours per day). According to the Portuguese Statistics National Institute (2019), the employment is divided through the value chain as follows: 79% olive cultivation, 12% olive oil production, 7% commercialization and 2% refinery.

This sector plays a very important role for a large part of the community, since it employs around 1,2% of the total world active population, i.e., 35 million job positions. Per year, this industry generates approximately between 9.500 million euros to 13.500 million euros, worldwide. Information segmented by different continents can be consulted in Table 1 (Vilar, 2019). It should be noted that the number of persons needed for agricultural work in the traditional olive plantation sector is expected to be higher and less constant than in the one observed in modern olive plantations (Salomone & Ioppolo, 2012). Nationally, the olive oil industry influences the agri-food business with a positive value of 144,405 million euros, counterbalancing the negative results (-3.460 million euros) previously presented in 2017 (Vilar, 2019).

The summarized information given above can be observed in Table 1.

Table 1- Turnover, employed persons and percentage of active population per continent (2013-2017 average) (Source: Juan Vilar Consultores Estratégicos, 2019)

Continent	*Sales Volume (in thousands of euros)*	*Employment (number of persons)*	*Active Population (%)*
Africa	2 235 243 04	4 472 520	2,15
America	481 239 13	7 218 587	1,31
Asia	966 037	7 734 699	0,42
Europe	872 873 963	14 906 202	7,47
Oceania	743 6192	1 115 429	5,78
Total	11 529 244 09	35 447 437	1,21

An intergovernmental organization was established, denominated International Olive Council, with the intention of cooperating with olive oil supply chain different parties, where Portugal is one of the founding countries. The membership is only accessible to Governments of States or to international organizations who, throughout its course of action, have encouraged external companies to share their empirical knowledge about the operational practices. This promotes communication and negotiation, sets new and beneficial partnerships worldwide, in addition to accomplishing national and international uniformity in legislation, quality, organoleptic expectations, reliability, accuracy. All of this is possible through international agreements, including commitments from both sides, that produce high level incentives to mitigate livestock sector emission and ensure mitigation effort is shared between the different sectors of the economy. Table 2 and Figure 3 are the result of IOC statistics, concerning how olive oil's production is distributed worldwide.

Table 2- World's Olive Oil Production, adapted from 2016 to 2020

World's Olive Oil Production (2016; 2020)

Production (in 1000t)	**2016/2017**	**2017/2018**	**2018/2019**	**2019/2020**	**Average**	**Average (%)**	**World (%)**
World	2561	3379	3262	3207	3102	3.1	100
European Union	1752	2188	2264	1924	2032	9.9	70
Spain	1291	1262	1790	1125	1367	16.8	50
Greece	195	346	185	275	250	5.9	8
Italy	182	429	174	366	288	-11,40	8
Portugal	69	135	100	140	111	-10,10	3

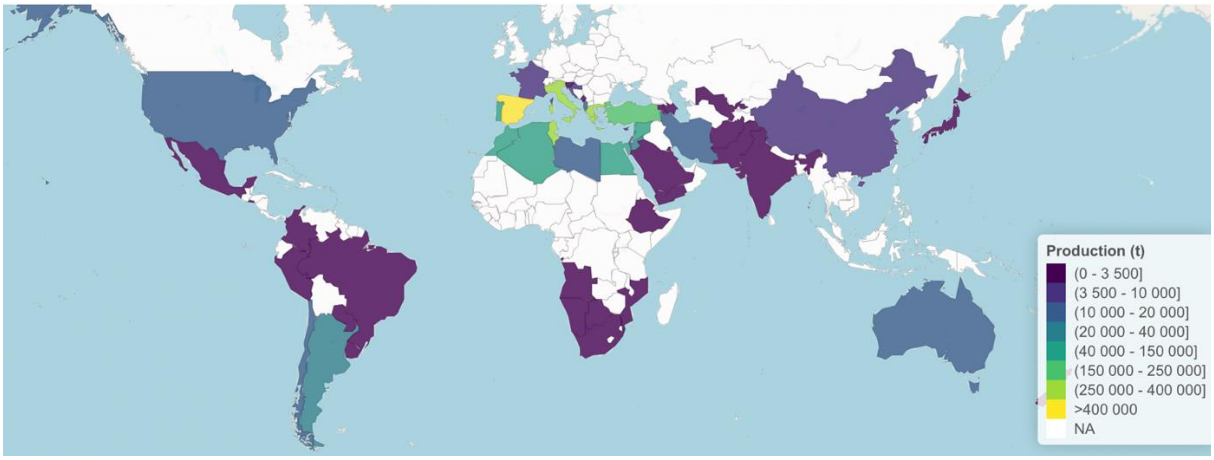


Figure 3- World Olive Oil Production distribution (Source: IOC, 2020)

In the 1960s, olive oil was considered to not have as many health benefits as other fats or edible oils available on the market had. This theory was a major downturn in this sector for every party involved, causing many of them to leave this business behind. This belief was then ultimately discredited with a number of secondary studies in the 1980s. Olive oil was again brought to light as a clear choice for cooking usage. After this, it was possible to observe a complete swing, from an industry that was becoming obsolete to a booming business with a demand twice the actual capacity of production (Salomone & Ioppolo, 2012). Thus, the government enforced some restructuring programs and additional political policies, as the basis for financing measures that would support agricultural investors to restore and replace the previous abandoned olive traditional plantation fields with more modern (intensive or super-intensive) plantation. Plus, the introduction of chemical fertilizers crop-protection products, herbicides, and modern irrigation systems of specialized machinery were enforced in this sense (mainly in operation such as harvesting and pruning). The implementation of more automated systems is leading, and will continue to lead, to a considerable reduction in manpower necessity. In this sector, employment is seasonal and poorly paid, and it is usually performed by aged populations or immigrants. On the other hand, an investment on modernization will eventually cause the company to grow the production capacity, efficiency/ productivity rates and quality of the final product will be exploited (Vilar, J. et al. 2019).

In Portugal, it should be noted that the sales volume increased by 147.2 million euros in "Animal or vegetable fats and oils" industry, summing up to a total of 172.5 million euros, holding in 2018 the best industry position (Monteiro, 2015). According to the latest statistics, the 2019/2020 national agricultural campaign released by SIAZ, presented a newly historical maximum of olive oil production levels, reaching 140.5 thousand tons. The number of olives worked at the mills increased by 33% compared to the previous season, and its average olive oil yield increased from 13.4% to 15.2%. This resulted in a 51% increase in the volume of olive oil produced.

Figure 4 represents the Olive Oil production per region in Portugal, and it is seen that one of the regions that is notably on the top position is Alentejo, who currently holds the number one position in terms of efficiency, levels of production/exportation, and an unrivalled rate of development when compared with other regions. According to the latest Agricultural Statistics (INE, 2016), there were about 347,093 ha of olive plantations in different production typologies (traditional, intensive and super-intensive). About 6% of this area corresponds to intensive and super-intensive olive groves systems, located mainly in the Alentejo region (GPP, 2017). According to the same statistics, in 2016, approximately 744,255 hl of olive oil were produced, that is 68,218 tonnes of olive oil, representing an increase of 11% over the previous year campaign (INE, 2016). The Alentejo region, noticed an increase in intensive and super-intensive olive groves in production, recorded a 64% increase in the volume of olive oil production and strengthened its top position, representing 88% of the total national production (SIAZ, 2020).

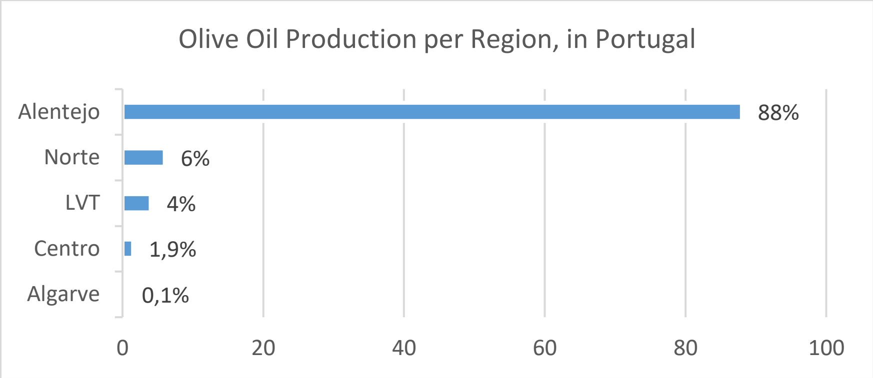


Figure 4- Olive oil production per region, in Porgugal (year 2019-2020)

In summary, some of the aspects that have contributed for general sector expansion were the positive developments in olive oil prices, national and international recognition of Portuguese olive oil quality, increase in domestic consumption per capita, exportations growth, leading to an important economic growth sector (GPP, 2017). As can be seen from Figure 5, Portugal's production, consumption and export volumes seem to have increased steadily over the past two decades, while consumption is considered stable. Production exceeded consumption for the first time five years ago.

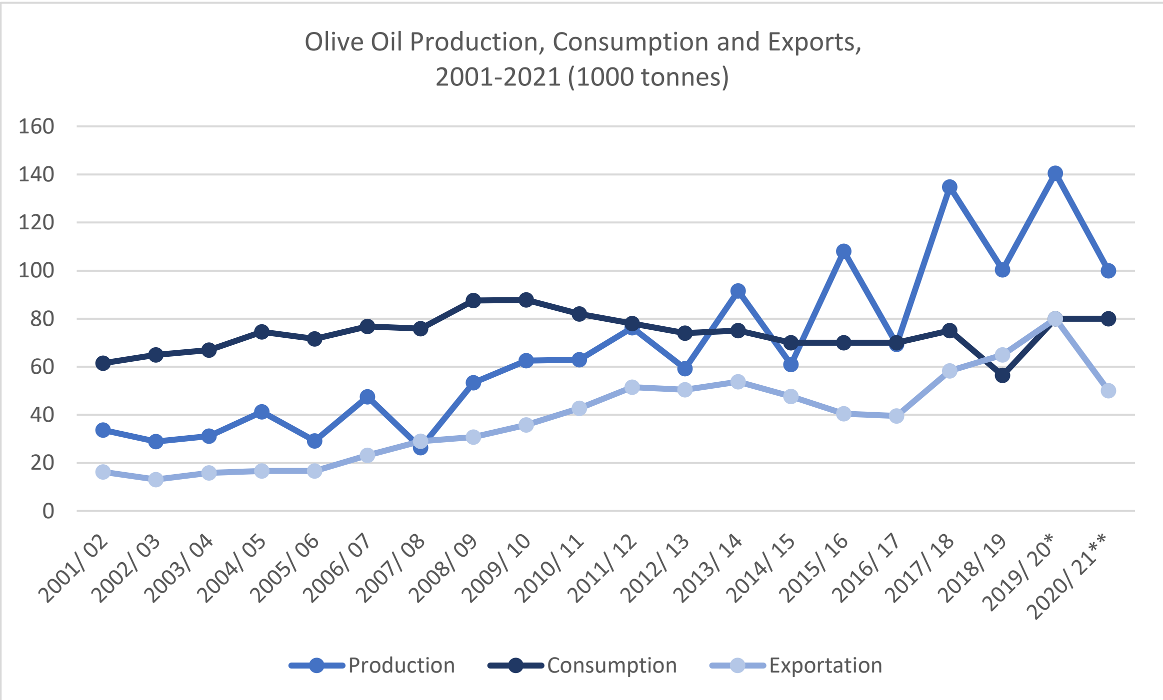


Figure 5- Olive Oil Production, Consumption and Exports, in Portugal from 2001 to 2021 (1000 tones)

Based on production, importation, exportation levels and domestic consumption analysis, Portugal could still increase its production area by about 42% compared to the current dimension (Vilar, 2019). Specifically considering Portugal exports situation, in 2018, exportation of Agricultural and agri-food products sector (except beverages) increased by 4.1% compared to the previous year, translated into a gain of 4,626.8 million euros (INE, 2019). Animal or vegetable fats and oils were the sectors that registered the 2nd highest increase, reinforcing its position as the main group of products exported by Portugal in the set of Agricultural and agri-food products, with an overall weight of 17.6%. This increase contributed mainly to Olive Oil, which maintained its position as the main product exported in this sector (around 71.3%). According to data from Casa do Azeite (2018) the majority of Portuguese produced Olive Oil is destined to Spain (44%), Brazil (27%) and Italy (18%).

1.2 Objectives

As previously described, nowadays olive oil is widely used for cooking and industrial purposes, causing the business to continuously grow worldwide. Unfortunately, the majority of companies does not include a management plan for adequate disposal and further treatment processes of the by-products originated by this industry (EMF, 2015). The process's design depends on the type of by-product that is generated, which is directly correlated with the olive oil manufacturing process and its quantity. By-products when not treated, are harmful to the environment and the tendency is for their volume to increase. Energy consumption dependency is also increasing, and the use of secondary energies is already our present future. Nonetheless, organizations still highly make use of primary energies, with a main emphasis on fossil resources, consequently, leading to scarcity of these natural resources. In addition, there is the problem of high environmental impacts associated with its use. CE promotes waste recovery for as long as it is possible to extract the most value from it. Considering the overall efforts made to stimulate waste recovery, the share of recovered waste is increasing, currently representing a major part of waste management systems, and growing. Nonetheless, further efforts must be made in the future.

It is hoped that this thesis contributes positively to the scientific community by addressing topics that are currently under-researched. Firstly, viable revalorization processes alternatives for one of olive oil's production byproducts, olive pomace, will be discussed. Next, concepts related to Industrial Symbiosis, Supply Chains, Supply Chain Management, and Circular Symbiotic Supply Chains will be clarified in order to better understand the upcoming work. Also, which are the enablers for the creation of Industrial Symbiotic Supply Chains, understood as being composed of three or more intra-relationships, focused on converting waste into future raw materials for other industries, while drawing benefits for each part. Foremost, the major goal of this research is to identify significant blockers that may hinder the establishment of this type of relationships, or later, its endurance, within a SC, more specifically in the Olive Oil Supply Chain. Finally, additional developments for organizations interested in forming these relationships are recommended, as well as methods for determining whether a relationship(s) is beneficial to the parties involved.

In summary, this work aims to present and clarify the importance of this problem through the following objectives:

- Describing the problem, the object of study, and the motivation for the work.
- Characterizing the case study and the supply chain network environment.

- Presenting a literature review on important matters such as: supply chain, reverse logistic, industrial symbiosis, supply chain symbioses, sustainability, environment, social and economic dimensions, bioeconomy, circular economy.
- Gathering barriers that hinder the establishment of industrial symbiotic relationships described in the other researches.
- Providing recommendations to overcome the barriers identified, or at least provide methods to better analyze if a certain relationship is suitable or not.

1.3 Study Structure

The present project dissertation comprehends the following four chapters:

- 1st Chapter: project’s introduction, which describes the problem context and the motivation behind the study case, as well as objectives and the project’s structure.
- 2nd Chapter: case-study, within the Portuguese market, of an operating network for the collection of by-products derived from the olive oil’s production industry. It is taken into consideration fundamental sustainability policies for each type of by-product that can be produced, collection, transportation and management methods that can be applied when the waste production is not avoided. This includes the characterization of network’s agents and their respective roles. Challenges for companies in the Olive Oil market are outlined.
- 3rd Chapter: literature review, in this chapter several concepts that matter to the present issues, once explored by other authors, are exposed.
- 4th Chapter: key stakeholders for this case study are identified and its role within the SC is observed. Then, several barriers for the establishment of simple symbiotic relationships are generalcy discussed and transposed to supply chain level. These barriers are then supported by recommendations on how they might be addressed or minimized.
- 5th Chapter: finally, the main findings of the work and future directions for work development are presented.

2 Case Study Overview

This chapter provides a brief overview of the most relevant concepts considering the issue at hand. Given the globalization of olive oil consumption, the industry has suffered an intensive growth, consequently, production has also been growing over the years, mainly in Mediterranean countries such as Spain, Italy, and Portugal. Accordingly, with the study: *"Alentejo: A Liderança a Olivicultura Moderna Internacional"* (2019), over the next 10 years, Portugal is expected to be the world's leading reference in modern and efficient olive growing, and possibly the 7th largest in area, and the 3rd largest in world olive oil production. To sustain this intense growth, it is necessary to have a well-planned integrated network. This study will analyze if positive outcomes concerning the three sustainability dimensions: environmental, economic, and social; can be originated through building appropriate relationships within a cooperative and symbiotic supply chain. It is hoped that from these emerging relationships, organizations are able to together be responsible for the optimization, designing, implementing and managing an integrated system that will ensure the correct routing and use of olive oil industry by-products. There are some responsibilities that companies should have into consideration. As entities responsible for the management of an integrated system, in this case, olive oil manufacturing, they should be encouraging the application of the following measures while acting in conformity with legal requirements for efficient waste management (Zero Waste Europe, 2015):

- Prioritize substantial and reliable relationships with each stakeholder that has an active role within the SC and implement a farm-to-fork strategy to draw a shorter supply chain by cooperating with local and sustainable suppliers/ retailers. Prefer simplicity rather than complexity, when deciding about materials and products
- Include prevention and recycling operations by extending the scope of Extended Producer Responsibility (EPR).
- When reformulating a supply chain of a certain industry, transforming it into a more sustainable approach, that focuses on the elimination of disposable products but sets minimum requirements for products in terms of toxicity, sustainability, recycling, and refurbishment. The framework should include economic benefits and recycling targets to promote the development of a sustainable product.
- Work on digital technologies to centralize information about material flows and improve and assist the communication between circular manufacturing and distribution networks.

In order to efficiently organize the case of study, this chapter was organized into three sections. The first is divided into five subsections, compromising the olive oil's production processes will be broken down, exposing the system's most important essential activities, inputs, and outputs. The second is an elucidation of potential transformation alternatives for olive oil byproducts. The third and last classifies the problem to be addressed in this work.

2.1 Olive Oil Management Integrated System

The olive oil's production can only begin when the olives are harvested and transported to plants usually located nearby, so that the fruit can be labored as soon as possible in order to maintain its quality and safety, since its lifespan is extremely short (about 3 days). If the olive is not labored in this specific period, the final product quality can be damaged, since it may lead to the appearance of unwanted molds, overheating, undesirable hydrolysis, or many other hazardous consequences (Nunes et al., 2016). Therefore, it is essential that the information's flow through the whole supply chain is strictly connected so that the material's flow over the different operations: from harvesting raw material, to then transport it to the plant where it will be handled immediately or stored for a very short period of time until it is handled to be transformed into the final product. The product is then shipped to the customer and made available in the market (Distribuição Hoje, 2020).

2.1.1 Olive Oil's Raw Material Producers

In order to ensure that the growing demand is met, the olive plantation was transformed into intensive cultivation in the past few years, with great significance in remote areas such as the northern Alentejo region. Even though modern practices are being implemented and used in some olive oil mills, there is always room for continuous improvement. The harvest period ranges from September through February, depending on climatic conditions, variety of olive trees, whether the olives are for table use or olive oil, optimal maturation point of the fruit, shipping/production rates, and manufacturing storage capacity. Nowadays, in more developed cultivations and manufacturing mills, there is a tendency of harvesting earlier than in the past, in the pursuit of the best possible oil quality (Vilar, 2019).

Agricultural practices are intrinsically involved in environmental impacts, with the greatest impacts on air, water, and soil. If these methods are not sustainable, the quality of nutrients and soil will decline, and they will quickly lose productivity due to increased erosion. When land-use plans and soil management are poor, farmers resort to fertilizers and irrigation systems. Although some farmers use irrigation methods, such as drip irrigation or precision irrigation, olive groves are usually grown without irrigation (dry method) to increase productivity. Throughout the agricultural process (cultivation, harvesting, and pruning), the consumption of fossil fuels associated with the use of special machines cannot be ignored. These special machines make a significant contribution to the emission of the main greenhouse gas, carbon dioxide (CO_2), methane (CH_4) and nitrogen oxides (N_2O) into the atmosphere (Salomone & Ioppolo, 2012).

In summary, the olive oil's life cycle main inputs introduced are energy: such as electricity and fuel when farming and plant machines are being operated, as well as the trucks used for goods transportation; water consumption in cultivation and manufacturing operation; and still during farming chemical products, including pesticides and fertilizers are often applied. Moreover, the main outputs are waste and/or by-products' production, air emissions, as well as water and soil pollution (Nunes et al., 2016).

During the cultivation process, olive trees are of 5 different operations: (i) pruning, (ii) soil management, (iii) fertilization, (iv) irrigation, and (v) pest treatment. When the fruit has reached the proper ripening stage, it is (iv) harvested. A graphical representation of the cultivation/ harvesting activities and their main inputs/outputs are represented next (Figure 6):

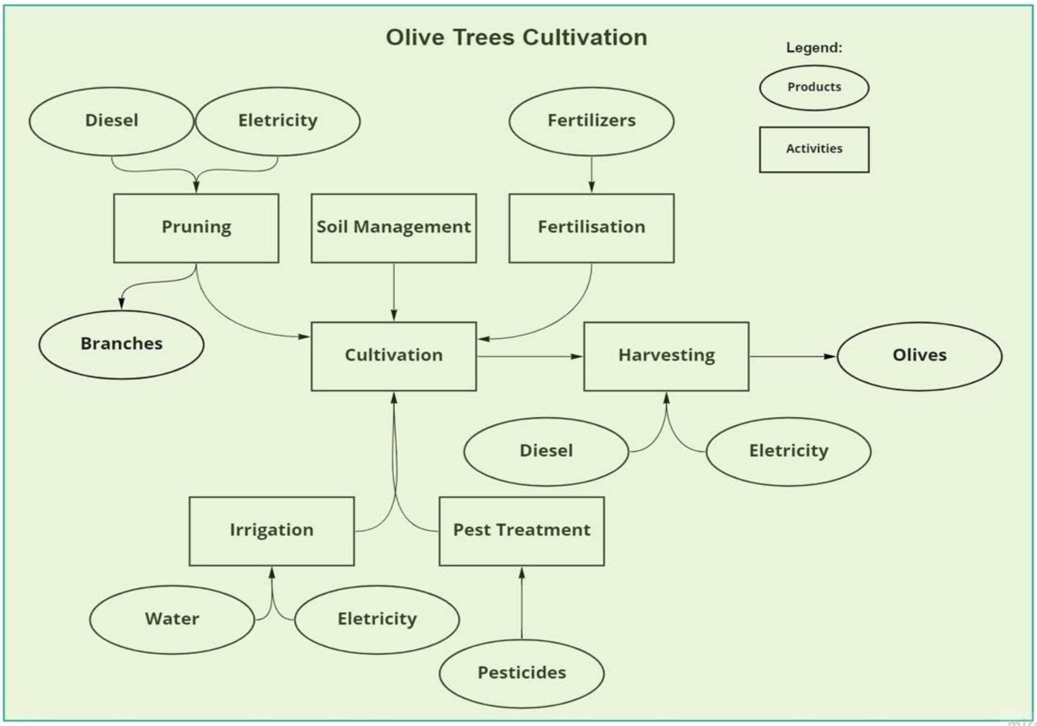


Figure 6- Olives' Cultivation

2.1.2 Olive Oil's Producers

The plant should preferably be located away from urban areas, public watercourses, areas subject to flooding unless sufficient safeguards are provided, and if possible close to farming locations. First, at the time of arrival at the transformation mills, olives are distinguished from table olives and olives used to produce olive oil. Undesirable materials, such as branches, leaves, and stones are separated from olives as they influence the final product quality and security, the fruit is then moved to a washing station, where a significant amount of water is used. Afterward, the actual production phase begins, and olives are exposed to pressing and centrifugation. The production of olive oil also includes energy and fuel consumption (Tsarouhas et al., 2015).

In Portugal, depending on the variety, climatic conditions and state of maturity of the fruit, the estimated average olive yield, (yield: ratio between the volume of olive oil extracted and the number of labored olives, which varies between 10% and 20% of the olive's weight, meaning that around 100/ 200 kg of olive oil is made from around 1 ton of olives. From SIAZ aggregated statistics (2019/2020), it was possible to calculate the annual yield since 2014/ 2015, as can be seen in Table 3 and Figure 7.

Table 3- No of olives processed and quantity of olive oil produced, from 2014- 2020; Statistics from SIAZ (2020)

	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	Average
Processed Olive (in tonnes)	358947	587227	430636	735908	623510	831457	594614
Extracted Olive Oil (in tonnes)	51190	89344	61870	119404	83829	126433	88678
Yield (%)	14,26	15,21	14,37	16,23	13,44	15,21	14,79

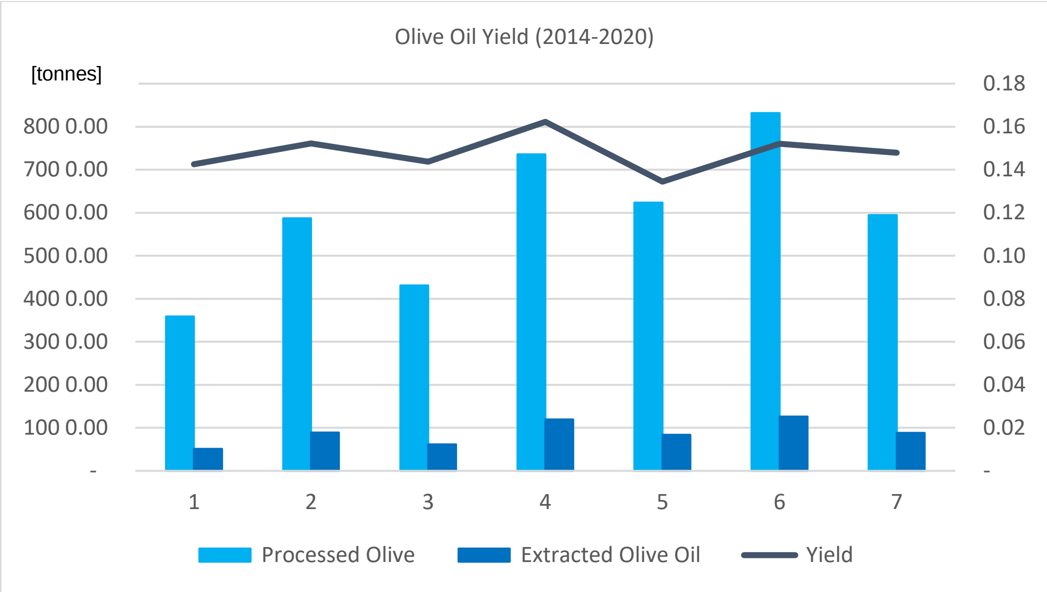


Figure 7- Olive Oil Yield, from 2014- 2020; Statistics from SIAZ (2020)

Olive oil's production is represented next in Figure 8 and 9. When olives enter the olive mill, the following activities happen (i) separation of inedible components by density; (ii) washing; (iii) grinding and beating/ mixing with the help of a mixer (iv) extraction of olive oil by centrifugation (separation of solid/liquid parts); (v) filtration to remove suspended solid matter, followed by (vi) bottling in portable bottles, according to with the order.

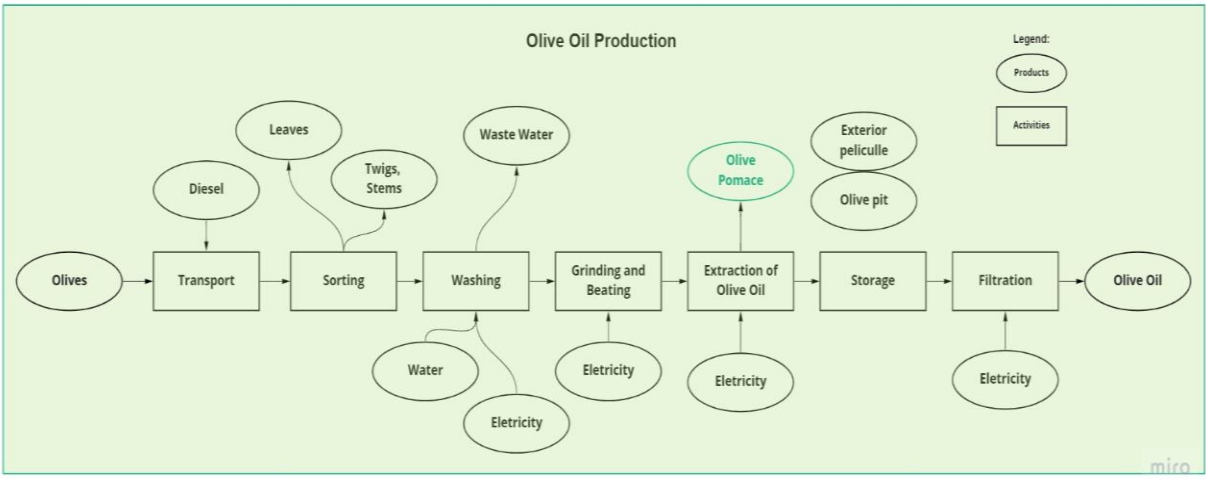


Figure 8- Olive Oil's Production

The pressing system is still used in some small plants that use hydraulic presses, but it is becoming an outdated technology. Consequently, it is being largely replaced by centrifugal systems, which can reduce olives storage time before being processed, reduce production costs and improve oil quality. This process produces a solid part- olive pomace (OP)- and an emulsion containing olive oil and water, which is then separated from the residual water (Olive

Mill Wastewaters - OMW). The two-phase system continuous centrifugation and the three-phase system continuous centrifugation have higher processing capacity than the pressing system, but also generate more waste and energy consumption. The difference between these two is that the oil part can be separated from the olive paste, in the first one without adding water, resulting only in the production of wet olive pomace (OWP) and a small amount of OMW. The three-phase system originates from olive pomace OP, olive oil, and a large volume of wastewater, as described in Figure 9 (Celma et al., 2007).

Whereas it is compulsory to have common standards for the self-monitoring of olive oil's quality and olive-pomace oil industry based on the codes of food hygiene practice of the *Codex Alimentarius* and the Hazard Analysis and Critical Control Point system FAO (2016). Olive oils must meet the legal requirements provided in the legislation throughout their shelf life concerning human safety, maintaining for as much time as possible their composition and characteristics, from production to final consumption.

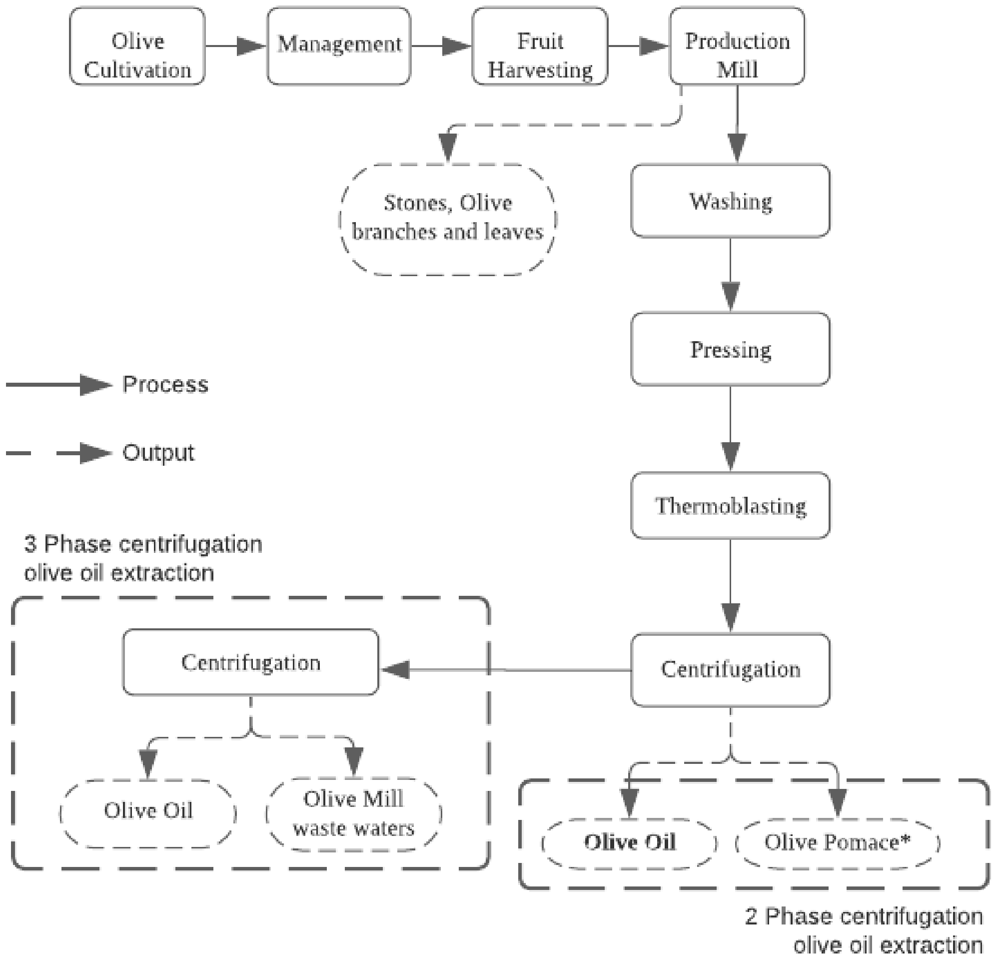


Figure 9- Olive Oil Production Process adapted from Celma et al. (2007)

Olive Oil manufacturers are the entities that hold olive pomace, after its production, until going to deliver it to a collection center or a certain entity comes to collect it.

2.2.3 Collection Centers

Collection centers can act as an intermediary entity between olive oil producers and retreaters, allowing collected products to be centralized in a single location. The need for centralization could arise from the need to accumulate a certain amount of product before sending it to the retreater, from a lack of stock capacity between the producer and the retreater, or even from a need to collect by-products from different by-product producers and then get them closer to the retreater's location. In this case, collection centers are licensed operators in charge of acquiring olive pomace from their holders and keeping them before sending them to recovery/recycling destinations.

2.2.4 Carriers

The primary resource flow is the onward flow of products, whereas secondary resource flows are goods that are recycled, retained, or reused (Luthra et al., 2022). This sub-chapter indicates key players, involved both in primary and secondary resource flow, that will perform olive oils' and by-products' collection/ delivery, respectively.

Contracted logistics services include collecting harvested fruits or waste generated from cultivation, from farm fields, and delivering to an assigned olive oil mill or collection centers/ transformation facilities, respectively.

When the olive oil production process is finished, the olive oil merchandise undergoes into the company's stock management or is picked up and delivered at retail companies (Figure 10). The distribution phase includes the transportation of raw materials to production facilities, by-products, and waste to local collection centers, disposal facilities, or landfills, and the distribution of olive oil to local, national, or international markets. Packaging is necessary before distributing the merchandise. Packaging's main functions are to contain the product, respecting its physical state and chemical nature, to protect, and conserve for longer periods of time by inhibiting chemical, enzymatic and microbial reactions, and to communicate with the consumer by labels. Packaging is the last stage of a product's production cycle, it includes primary packaging usually made of glass or plastic, which is in direct contact with the product, and is usually placed at the final point of production, with information geared towards the consumer regarding products' characteristics. Secondary packaging is made of the carton which protects, facilitates transportation and storage, and can transmit information to carriers. Waste management plans should include the treatment of bottle and packaging waste.

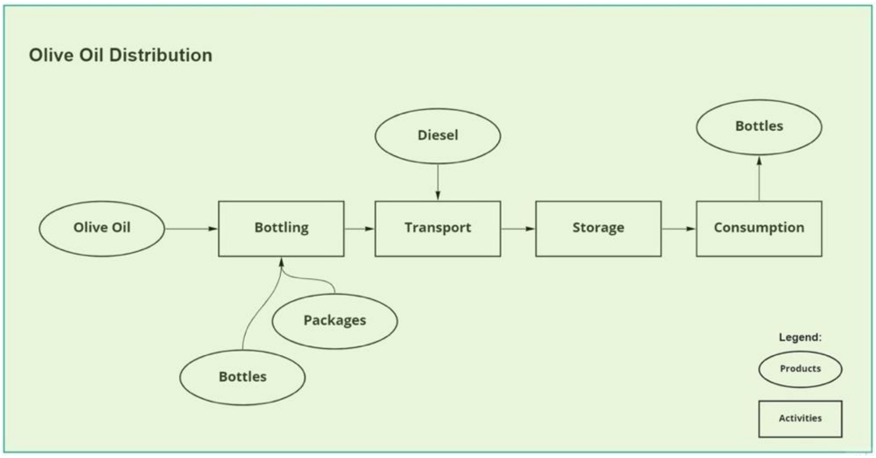


Figure 10- Olive Oil's Distribution

Whereas, when olive pomace is collected it does not need any specific container although transportation and storage temperatures should be below room temperature, as to ensure the product's stability. The carrier is supposed to deliver the byproducts to the recovery operator, who later is going to recover or recycle or dispose of the byproducts.

2.1.5 Recycling and Energy or Resource Recovery

Recently, the landfill tax has been increased by governmental entities, in order to encourage producers to build new solutions for waste disposal/ recycling and at the same time divert waste from landfills. Waste is considered the most abundant biological resource if it could be used as a raw material: this is the recommended concept for waste treatment facilities, given that manufacturing companies normally prefer to be focused on their core business.

When designing a network there are multiple questions that need to be considered, including auxiliary activities, collection centers, inspection and sorting, transportation to collection centers, and from the collection center to treatment facilities. The most impactful by-products from the olive oil industry are wet olive pomace (OMW) and Olive Pomace (OP), which combined with the right handling can be transformed into energy (e.g. biodiesel) and natural fertilizers (Figure 11). It is mandatory that measures are taken to ensure that by-products are safely used as inputs for new manufacturing cycles. However, waste management entities find it difficult to ensure that the quality of the final recycled product is uniform since by-products are retrieved from different farmers, manufacturers, and retailers (Celma et al. 2007).

Figure 11- By-products and Waste Management

2.1.5.1 Characterization of Resulting Waste from Olive Oil Manufacturing

Processing water and pomace oil production were once considered waste. Now if proper recycling measures are taken, they are regarded as by-products due to their economic and environmental value. However, local producers often cannot properly dispose of these by-products, and are not often used to the extent that they could be used (Salomone & Ioppolo, 2012).

OP can be obtained through a traditional pressing or/ and a three-phase system. Normally, it is sent to a pomace oil extraction plant, where after a drying process, the oil can be extracted with hexane. OWP is composed of a greater percentage of water and can have a high calorific power, which can increase to higher treatment costs since the drying process requires higher energy. In the first case, farmers compost OWP in open areas, producing stable fertilizing organic matter that is free from pathogens, the compost can be watered if necessary and homogenized with a tractor for about four months. This fertilizer is used for maintenance fertilization during cultivation because it can increase the effectiveness of the applied mineral fertilizers and improve the chemical, biological and physical properties of soil nutrients. The chemical composition of the olive oil differs depending on the fruit species, cultivation method, harvest time, and oil extraction. The OMW is directly used in the field. Due to its high nutrient content and high antibacterial ability, it is a positive way to improve OMW, but due to its high mineral salt content, low pH value, and organic compounds, it can also have a negative impact on the soil. Last but not least, the reverse supply chain approach also puts tremendous pressure on groundwater. The spread of wastewater on land poses a serious threat to soil pollution, leading to a decline in biodiversity and potable water problems (Salomone & Ioppolo, 2012).

2.1.5.2 Characterization of Energy Sources

The two sources of energy required in olive mills and cultivations are electricity and fuel. From the moment the olive tree is cultivated until it is bottled and forwarded to the retailer/ consumer, all machines and vehicles work based on electric power or fuel. Over the years, energy efficiency and energy saving, or the development of energy-generating techniques have become important objectives in the EU. For example, the separation process can be more efficient if the production system has installed integrated Direct Drive separators that effectively separate the various components according to their density. Recently, new technology is being developed to replace vertical centrifuges with decanter tanks that use gravity as the main source of energy. By using this method, it is possible to reduce energy and water consumption, its main drawback is more time-consuming and requires more available space to install the decanter tanks. A few years ago, renewable energy became more popular and recommended as a power source for different types of facilities, including olive oil mills. Mediterranean countries have an infinite source of energy, sunlight, and in some cases wind. By using wind turbines and photovoltaic cells to capture and convert, respectively, the wind's and sun's rays into electricity, solar panels transform light into usable energy. From an economic and environmental point of view, this solution can save energy, and it can also reduce air emissions (Donner et al., 2020).

2.1.5.3 Characterization of Water Consumption

The olive trees' cultivation phase is not very demanding in terms of water, as long as soil management, regarding nutrient balance, is done properly. But even so, different irrigation techniques should be considered, techniques that can promote more efficient water use.
Precision irrigation is starting to become widespread, as it delivers water and nutrients directly to the roots in measured quantities, keeping the root zone at optimal hydration levels. It also reduces water and nutrient waste, normally waste on its surroundings, and maximizes the use of inputs. These systems are based on the water absorption capacity of the soil and the consumption of the plants so that the air-water ratio in the soil is perfect and the nutrients are kept where they are needed. Information systems were developed that can be installed on-site, they enable farmers or managers to be aware of the moisture content of soil and plants, air temperature, relative humidity, radiation, wind speed, calculation of laminar humidity and evaporation and to automatically activate or deactivate irrigation systems. In olive mills, as previously seen, water can be saved if the two-phase system of continuous centrifugation is implemented, rather than the three-phase system of continuous centrifugation (Tsarouhas et al., 2015).

2.2 Solutions used in the olive oil sector for Olive Pomace transformation/ valorization:

Accordingly, the potential transformations of the effluent from two-stage mills, wet pomace, must be evaluated in order to determine technical feasibility. One crucial stage in determining process requirements is to define the product's morphological characteristics in order to determine which valorization method is most suited for the particular by-product. This residue is a low-cost source of phenolic compounds, but it has high phytotoxicity and organic load, an acidic pH, and high moisture content, which increases the costs of transportation and treatment enormously. What we must underline is that the woodier ones, rich in cellulose and lignins, have the best features for energy production, as evidenced by annual weight production and the relationship with its co-responsibility in millions of oil equivalents. For example, the least lignified materials are usually the most easily biodegradable, and hence have a greater potential for application as organic modifiers. As a result, we can create a link between waste and its expected degradability, making these two destinations compatible (Moral et al., 1995.):

- Woody materials, excess, and residues high in sugars and alcohols for energy and fuels.

- For use as conditioners and fertilizers: biodegradable products with high nutrient content.

The policies imposed on a product's transformation, storage, and handling process have to be examined and followed, these might be regarded as quantitative or qualitative, for example, an interval of temperature or a minimum or maximum level of contamination, respectively (Kosmol et al., 2021). Also, there is one aspect, from the economic point of view that should be considered when looking for an application of organic waste: it is potential for obtaining energy or as a conditioner/ soil fertilizer. It should be mentioned that the majority of by-products produced are either composted or are considered inputs for biodiesel production, with the resulting goods meant for agricultural applications or animal feed and energy alternatives, respectively.

- **Composting**: selling for fertilizer or animal feed (pasture)
- Subtract Extraction (Cosmetic industry)
- Livestock industry (livestock feed)
- **Biodiesel production**
- Pomace Oil Production

- other non-return treatments (e.g., landfill, incineration)

Good practices such as **Composting** should be included prior to application to the soil since, due to its high moisture content, acidic pH, pro antimicrobial and phytotoxic properties, and a balanced Carbon/Nitrogen ratio (C/N), has a higher humic substance content than the original product, olives. Composting allows for minimizing the accumulation of waste materials, the incorporation of organic nutritional elements into crops, reducing the need for mine and chemical fertilization**,** and lastly can also help farmers' economic situation by lowering expenses in the purchase of inorganic fertilizers, which are sometimes more expensive (Payr et al., 1983). What distinguishes composting from the natural process of organic matter degradation is human intervention in the form of appropriate changes to the various relevant factors, as well as the development of techniques that speed up the decomposition process and provide high-quality material for the soil (David Catita, et al. 2021). According to the ECN Status Report 2019, the European body European Compost Network estimates that between 118 and 138 million tons of bio-waste are produced annually across the European Union, with only around 40 percent effectively transformed into organic compost, putting the European Union in last place in terms of per capita quantity. This transformation method enables for easier, safer, and less odor storage, and also because of the lower moisture content and the loss of volume, it allows for lower handling and transportation costs as well as greater ease of application (David Catita, et al. 2021).

Another good practice is **biodiesel production**, it consists of the agricultural and manufacturing recovery of by-products/ residues from agribusiness, contributing to the improvement of functional and environmental performance that concerns companies in the sector, leading to agronomic and environmental benefits. Biodiesel is produced through a chemical process and can be obtained from various crops, used vegetable oils, or animal fats. It can be directly injected into diesel engines with little or no modification. Benefits include significantly reduced emissions of pollutants related to global warming and acid rain compared with conventional diesel, but biodiesel will also increase emissions of nitrogen oxides, which are a key component of smog. Some companies are concerned with how they can produce more fuel with a cleaner burning, by using products that would end up in landfills and now are being used as raw materials for the production of fertilizers, agricultural machinery, and vehicle engines (Cohen, 2007).

2.3 Problem Characterization

The purpose of an olive oil’s byproducts management system is to ensure the correct end or revalorization of these products’ life cycle. This will require the promotion of olive oil byproducts retread, recycle, or valorization with energy/material recovery, which can be solutions for effective waste management, to avoid other forms of disposal, harmful to both the environment and public health such as landfill disposal, as well as generating additional benefits for the company.

While implementing and managing a stable network, it is needed to ensure that the network is composed of integrated multiple entities namely, the olive oil producers/ holders, collection centers, carriers, recovery operators, and potentially new buyers of the energy/ material recovered. Together, they should be able to efficiently interact with each other to maximize the collection of olive oil by-products from its sources and to avoid bottlenecks along with the network that keeps them from being recovered, creating unwanted accumulations of stock that later may disable olive oil production capacity due to legal reasons.

Imagining the implementation of a good practice scenario, which implements the solutions that can help bring the circular economy to the supply chain, specifically the olive oil supply chain, and supports the efficient use of resources and materials (or using waste as the input for another product whilst eliminating “take- make- dispose” paradigm). In this scenario, the supply chain composed of multiple collaborators will, not only, spare the environment, but also the companies will benefit financially, by saving money or having an additional source of income.

This work aims to address issues stated in the previous subchapters, specifically the ones concerning the accumulation of olive oil production by-products in the mill processing phase, the olive pomace. The case study that is performed within this thesis proposes improvements to overcome identified barriers when it comes to building or maintain a multiple relationship system.

3 Literature Review

This research brings together the literature on the responsibility of suppliers, manufacturers, and customers, and proposes the concept of social sustainability and waste valorization upstream and downstream the supply chain (SC), mentioning the creation of cooperative bonds between different stakeholders as one of the answers towards sustainability. This chapter centers on a literature review on the relevant concepts that are significant to the present issue. This review is divided into two different sections. The first, concerning supply chain, aims to address the concept of supply chain management and waste framework. The second, sustainable supply chains, since the challenge involves an IS network that takes into account the three elements of sustainability. In the latter, topics like Bioeconomy, Circular Economy, Closed Loop Supply Chain, Triple Bottom and Industrial Symbiosis.

3.1 Supply Chain

A supply chain is a network of entities, which can be composed by individuals and/or organizations, that are engaged through upstream and downstream connections, in several processes and activities that, together, add value in the form of products or services, later delivered to a client. A logistic network consists of suppliers, manufacturing centers, warehouses, distribution centers, and retail outlets, as well as raw materials, work-in-progress inventory, and finished products that flow between the earlier mentioned facilities (Simchi- Levi et al.,1999). A brief representation of a SC is made available in Figure 12.

Figure 12-Traditional Supply Chain

Logistics is an integral part of the Supply Chain Management (SCM), the configuration of the logistics network has a significant effect on the overall performance of the supply chain. It is responsible for coordinating activities, such as warehouse and resources management, updating information systems, plan collection and reception points, defining the target market, analyzing consumer profiles to deliver a better-quality service, implementing disposal methods, and monitor robustness, efficiency, and effectiveness (Carvalho, 2012). Logistics network design decisions include determining the numbers, locations, and capacities of facilities and the quantity of flow between participating entities, such as carriers, warehouses, wholesalers, retailers, and consumers.

When configuring any supply chain, the forward flow design has to be considered simultaneously, with the reverse flow design. In the past, producers were only concerned about the forward flow: delivering the right product, with the right amount and quality, however, what had happened after the product was purchased or used was not their concern (EMF, 2015). There are now fewer and larger companies among food producers, processors, and retailers due to today's vertical integration and competitive business environment, which have resulted in increasing cooperation between members at different levels of a supply chain (Yakovleva, 2007). Also, the growing market share, or expanding within the same industry, by integrating within the same level of the supply chain, sometimes merges among individual companies or acquisitions can occur, which is named horizontal integration (Cuafano, 2020). A representation concerning horizontal and vertical collaboration is made available in Figure 13.

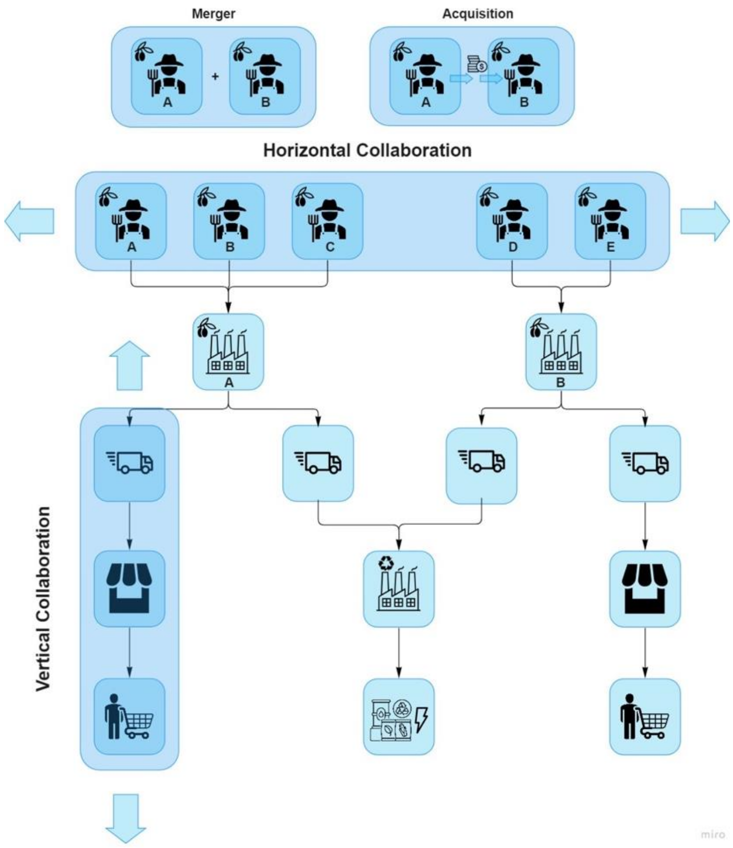


Figure 13- Horizontal and Vertical Collaboration adapted from Cuofano, 2020

3.1.1 Supply Chain Management

Companies began to recognize that they could no longer operate as single entities, but rather as part of a network of enterprises collaborating to maximize consumer experience (Teixeira, 2019; Martin, 2011; Min, 2015). The main stakeholders in agri-food supply chains are usually farmers/producers, food industries, distributors, retailers, and consumers, as represented in figure 14. In addition, several external entities, such as government agencies, non-profit organizations, food and industry representatives, and investment firms, serve as secondary partners. They may or may not participate in supply chain operations, but they frequently have a variety of effects on the business system that handle materials, data, and cashflows among different parties (Dania et al., 2018).

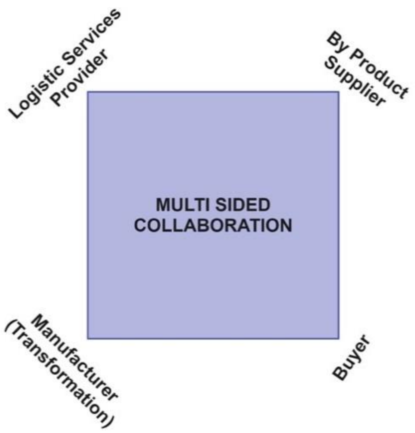


Figure 14- Multi-Sided Collaboration

According to Porter (1985), the value chain is a systematized technique for representing a company's beneficial primary (divided into inbound logistics, operations, outbound logistics, marketing and sales, and service) and support activities that, together with the company/ supply chain capabilities, originates a competitive product or service. Strategic capabilities can be defined as the resources and skills required for the survival and development of an organization. If a company wants to accomplish a competitive advantage by providing value to customers, managers need to understand what efficient actions can create value, which to adopt, and which not to. Traditionally, the strategic capability of a company or industry can be analyzed through the value chain, network structure, activity mapping, and benchmarking (Johnson, 2008). A company can differentiate itself from other companies by competing at lower prices or by providing better services than other competitors, or even, by taking sustainable measures to reduce its impact. Six strengths that a company must have to maintain a strong position in the SC are: reliability, adaptability, resilience and right partnerships management, sensing and responding, and managing the unknown (Carvalho, 2012).

The collaboration among varied stakeholders is critical for gaining a competitive edge and achieving better environmental, commercial, and social results. When dealing with complicated sustainability requirements in agri-food supply chains, effective and high-quality cooperation for sustainable agri-food supply chains may enable farmers to have access to the same resources, opportunities, and advantages as other supply chain stakeholders. It is critical to have synergetic and coordinated interactions among diverse stakeholders in order to achieve sustainability in the agri-food supply chain (Dania et al., 2018).

The forward logistics flow is characterized by the set of activities used to produce, transform, and distribute a service or a product following a downstream route. It only ends when a product reaches its end-of-life cycle, either through product consumption or disposal. Every stage of the production chain needs to be considered in a harmonized way, and not just one specific step, from resource extraction to waste management. Logistics operations are divided into two different activities: inbound and outbound logistics. Inbound logistics cares about receiving, storing, and distributing inputs to the product or service including material holding, stock handling, monitorization, and transportation, among others. While outbound logistics are activities concerned with materials collection, storage, and distribution of a given product to customers, (e.g., warehousing, handling, distribution) (Simchi-Levi, 2003). Figure 15 is an example of a Value Chain.

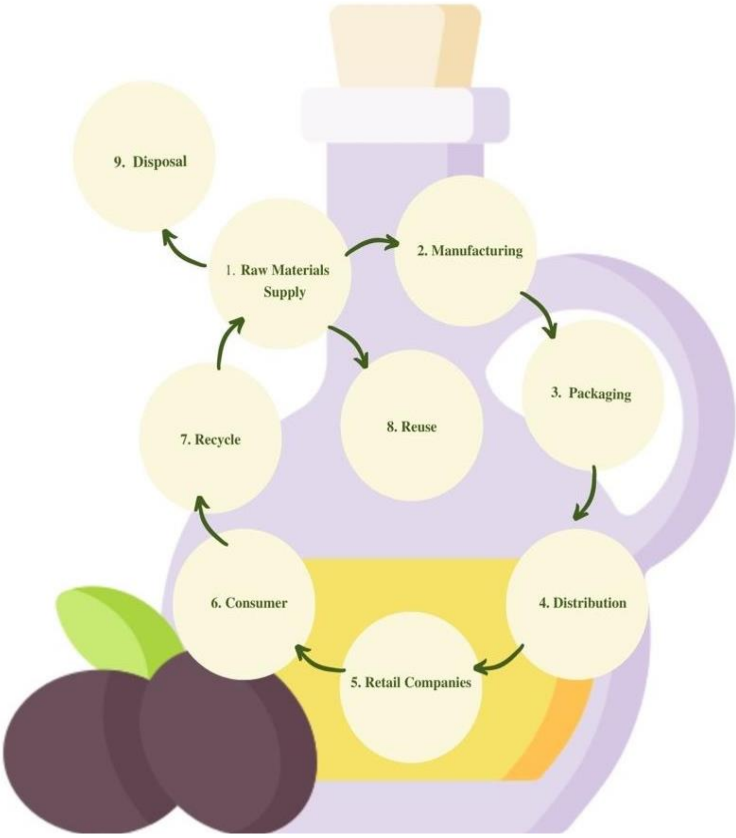


Figure 15- Olive Oil's Value Chain

Another dimension of SCM is risk management. Risk management is the process by which potential events that could adversely affect the company, or the industry, are identified. Risk mitigation plans can be formulated to be within the risk appetite in order to provide reasonable assurance so that the company goals can ultimately be achieved without major consequences. That being said, a risk assessment should be performed at all levels of a company's activities in the SC, by estimating the risk significance, the likelihood of the risk occurring and how the risk should be managed in case it occurs (formulating a mitigation plan). Whereas risk is only considered to have a negative outcome, uncertainty can cause negative or positive effects, but both are relevant issues to consider in a study on SCM (Simangunsong et al., 2012). From the perspective of operations management, building a flexible supply chain can reduce the risk of interruption due to supply and demand shocks. For example, uncertainty in a SC can be related to demand versus supply, transportation plans, price fluctuations, quality level, and customer service. In this case, the availability of industrial by-products is the result of a push process, which means quantity and the moment of time that it will be available is uncertain. As a result, there can be surpluses or shortages in different industries due to fluctuations in supply and demand and different seasonal characteristics (Morgan, M. G). Considering downstream flow, the agricultural market is particularly volatile, heterogeneous, and extremely sensitive to economic and financial fluctuation in levels closest to the customer (demand elasticity) (Martinez, 2019).

3.1.2 Waste Framework

Observing the global economy, perhaps the food sector is one of the best potential creators of natural and regenerative capital rather than only exhausting it in the long term. For billions of years, organisms have evolved, flourished and, at the end of their cycle, become "fuel" for the beginning of a new cycle (Donner et al., 2020).

Ellen McArthur Foundation defines circular economy as a "*restored or revived industrial system by purpose or design"* (EMF, 2015). Meaning that when implementing a circular economy-based system, a drastic change will occur at the level of the system, downstream and upstream without gaps (suppliers, manufacturers, retailers, consumers). The Ellen MacArthur (2015) has pointed out that the notion of a CE relies on three principles:

1) Preserving and enhancing natural capital by controlling finite stocks and balancing flows of renewable resources;

2) Optimizing resource yields by circulating products, components, and materials of the highest utility in both technical and biological cycles; and
3) Fostering system effectiveness by revealing and designing out negative externalities (Abreu & Ceglia, 2018).

The terms "waste" and "by-product" are carefully attributed, so that uniform policies and laws towards minimizing the negative effects of waste generation on human health and the environment can be implemented. Food supply chain waste (FSCW) is the organic flow of material produced for human consumption that is discarded, lost, or degraded primarily at the manufacturing and retail stages, including waste, arising. Food Waste (FW) is produced at every stage of the food supply chain, being more obvious at the retail and consumer stage, but this should not be ignored in other stages of the chain (Lin et al., 2013). It can be defined as products or product components that the holder intends to discard or is obligated to discard, ideally by implementing advanced valorization routes (CNCDA, 2017). Food by-products are secondary materials that arise from the cultivation and manufacturing stage (e.g. mill waste) or that are not edible (e.g. leaves, olive pomace), as well as consumer waste (e.g. packages) (Lin et al., 2013). A new organizational structure must be introduced to facilitate the implementation of the CE model (Esposito et al., 2018). The so-called 3R strategy (Reuse-Recycle-Reduce) must be applied to the entire production, consumption, and reverse logistics. The following figure highlights strategies that can be implemented in a CE (Figure 12).

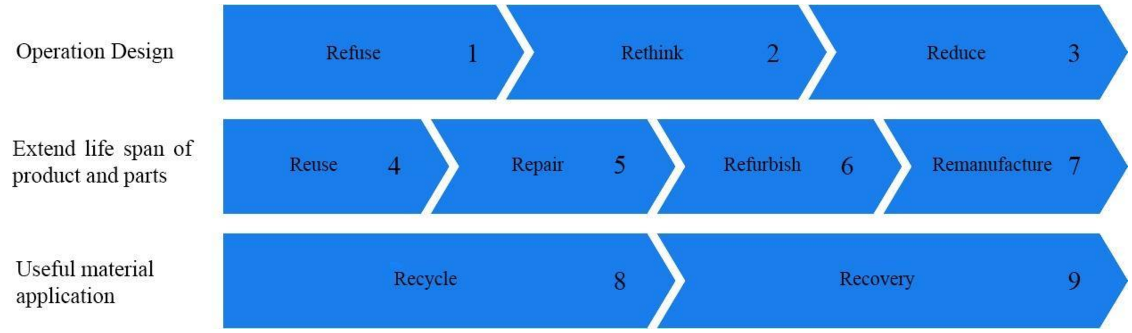


Figure 16- Framework on CE strategies, adapted from Morseletto (2020)

3.2 Sustainable Supply Chain

The Brundtland Commission, formerly the World Commission on Environment and Development, has developed the most well-known definition of sustainable development, which takes into account how a human being should behave in conformity with society:

"Development should meet the needs of the present generation without compromising the existence of future generations to meet their own needs" (European Commission, 1987).

Therefore, from an ecological-economic perspective, to be sustainable, means the development must be economically sustained (or efficient), socially fair (or inclusive), and ecologically thoughtful (or balanced) (Pearce & Atkinson, 1998). Having regard to this definition, sustainable management of a SC has to be aligned with shifting the focus from **labor productivity** to resource **productivity**. There are two reasons for resource scarcity: if demand continues to exceed supply, this will quickly lead to stress over the resource. On the other hand, resources may be stressed because their exploitation will cause external influences, either positive or negative. The government may have to intervene in the relationship between the producer and the consumer, if there is a need to reduce the consumption of a certain resource, on both sides (Di Maio et al., 2017).

According to the UK Sustainable Development Committee, a sustainable food supply chain produces healthy and safe products in response to demand. Moreover, it should support the viability and diversity of urban and rural communities and economies, while respecting the limits of natural resources. High standards of sustainable performance can be achieved by investing in renewable energies and reducing energy and resource consumption whenever possible. It is also important to ensure a safe and clean working environment, the training of all employees, and a high level of social well-being (Yakovleva, 2007).

In a business, the main goal is to optimize the system, in order to exclude the inefficiencies. Waste can appear in every stage of the SC, and can be seen as inefficiency of the system, not only the disposal represents a cost, but it is also a sign of a poorly designed production process and consequently, an unsuccessful planned SC. As product multiple-use mindset grows in popularity, companies begin to recognize that zero waste strategy can be key to success and durability.

To help companies, European Union decided to develop an effective infrastructure for collecting and sorting various supplier wastes such as resource banks, including secondary material flow plans for discarded items, that optimistically will dramatically improve the efficiency of the industrial ecosystem (Frosch & Gallopoulos, 1989). Some of the actions may be stated quite briefly: Circular Economy Action Plan (CEAP), complementary to the European Green Deal, including the Climate agenda, Farm to Fork, Sustainable chemicals strategy, and Zero pollution strategy. In the period of *"local pollution per industry"*, where environmental progress in the industry has been largely initiated by the government. As we enter the period of *"global social concerns*" (globalization), this is no longer a pragmatic approach. There is an unquestionable necessity to focus from local to global and from industry to society. It is not enough to increase recycling and look at partial reformulations when considering a circular complex system. If the goal is to create a more sustainable economy, it is also important to look for a complete reduction in storage and resource consumption, in other words, reduce socio-economic metabolism while respecting the three dimensions of sustainability: profit, planet, and people. For reaching an effective waste-free circular model, the current design should be reviewed and should move to an EcoDesign approach (a design that complies with the principles of ecological sustainability). Nevertheless, ensuring that the new circular model remains competitive when compared to the previous deprecated approach, linear single use products (Europe, 2020).

To do this, essential elements that impact the features and performance of collaboration, i.e. collaboration barriers, must first be identified, which may assist supply chain stakeholders in examining and managing the collaboration system for changes (Dania et al., 2018). Collaboration among organizations, as well as sustainable consumption and production, will be the next subjects for implementing sustainability into agri-food supply chains.

3.2.1 Bioeconomy

Bioeconomy is recognized as a very noteworthy contribution to the circular economy. This concept relies on progressing from a traditional fossil-based economy to a bio-based recovery from complex molecules of biomass previously considered residues from industrial processing of food, to products such as chemicals, organic fertilizers, biofuels, and eventually heat and power. Bio-based products are only considered better than fossil if food security is ensured, through transparency and traceability of waste recovery operations, including information concerning the risks and benefits, since it should be clear that the use of biomass is not a zero-impact activity (European Commission, 2018). The transformation of bio-based materials results in products denominated biodegradable or “green chemicals” that may be identical to fossil alternatives, or even become original products with entirely new functionalities and potentially penetrate in new markets, generating significant new sources of economic added value and future revenue streams in a booming bioeconomy.

For instance, an integrated biorefinery can convert olive oil by-streams into value-added products, and consecutively open up new opportunities to diversify the industry's portfolio. The establishment of these biorefineries aims to develop rural communities by creating local job positions and inclusiveness, it will also secure the future of olive growing and olive oil production, by making olive oil production more sustainable. Also, it will increase the diversity of products that farmers depend on and the profit they can get from their production, as to protect them from price fluctuations (European Commission, 2018).

3.2.2 Circular Economy, Closed-Loop Supply Chain, Triple Bottom

The closed-loop supply chain (CLSC) consists of two stages: forward logistics and reverse logistics, relevant for defining sustainable business strategies at the corporate level, whether from an individualist or collaborative perspective. The difference is that CLSC visualizes forward logistics and reverse logistics simultaneously, and the good or poor network design and operations planning of one directly affects the other. Products continue to flow to the end customer, but an increasing flow of products is returning. One of the reasons why RL systems are so essential nowadays appears to be ecological motives, particularly those resulting from political pressure. Figure 17 illustrates forward and reverse logistics are connected. Reverse logistics, according to Rogers & Tibben-Lembke, 1999), refers to the planning of a profitable return process for finished products and their information in relation to their life cycle, from the place of consumption to the origin point. Product holders are at the upstream echelon, which can be assumed to be the starting point of a reverse flow. Collection centers bulk returns from customers or waste/ by-products from producers, either dropped off by the product holders or picked up by the collectors' (Alumur et al., 2012). The item retrieved and inspected can have several destinations: reuse (optimal conditions), recycling, disassembly centers, remanufacturing, refurbishing, or disposal (poor conditions) (Lambert et al., 2011). Reverse logistics differs from waste management as the latter mainly relates to the efficient and effective collection and processing of waste (products for which there is no new use).

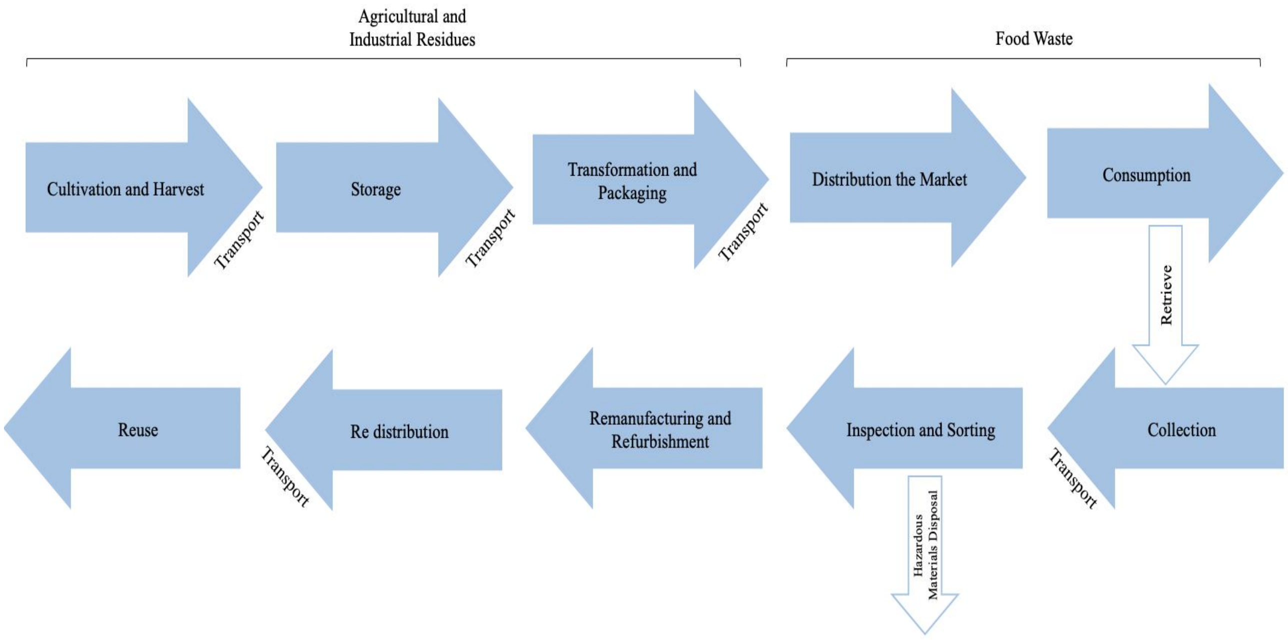


Figure 17- Forward and Reverse Logistics Flow

Manufacturers can use CLSC to benefit from retrieved and remanufactured products returned by consumers. In particular, refurbishment requires less energy consumption. In some cases, refurbished products may be more profitable and labor-intensive than producing new products (Chen et al., 2019). Despite the obvious advantages, trough, waste recovery, recycling, and improvement, the use of FW still has problems due to the following downsides and limitations: variable quantity, high water content, technical limitations, knowledge-based processing, skilled workforce, and the ability to transform it into valuable products (European Commission, 2018). Effective and inexpensive options are still being studied, legal and suitable infrastructure support for the transformation of perishable materials in the industry is still insufficient. The recognition and acceptance by the industry and the public will also be an important obstacle that must be overcome in the future.

Although sustainability has different meanings, the triple endpoint approach is a central concept that helps to achieve sustainability. In terms of economy, ecology, and society, the lowest network performance can be achieved (Moheb-Alizadeh et al., 2021). The contribution of economic indicators to human well-being is the subject of many studies and debates. The Triple Bottom Line (TBL) method aims to more accurately assess assets and use resources, so as to use capital as efficiently as possible. The concept is a triple added value method also known as the 3Ps -people, planet, profit (Roberts & Cohen, 2002).

As a consequence of low market prices, low quantities, seasonality, high transport costs, in some cases agricultural waste and by-products are not yet economically feasible. European Commission has adopted a circular, sustainable, bioeconomy strategy to assist these cases (European Commission, 2018). Circularity is an essential element of the European Commission's vision for an EU Bioeconomy. The circular business model does not principally aim at economic performance, but rather a favorable transition to a CE model conducted through Industrial Symbiosis. This could contribute to ultimately closing the loop by reducing the dependence on raw materials and minimizing or eliminating waste from the industrial system. For example, the prosperity of a biofuels manufacturing challenge relies upon its capacity to partner and engage with a wide panel of local players: farmers, agricultural cooperatives[1], industries, universities, and investigation centers. Inevitably, technological innovation alone no longer ensures the achievement of the financial goals - quite the contrary. First, the performance of the system by itself must be already efficient, and only then the way how technology is handled will dictate the vitality of the firm.

3.2.3 Life Cycle Assessment

As waste reduction, recycling, and the use of renewable energy are measures that tend to avoid waste and improve environmental impact, the Life Cycle Assessment (LCA) is considered the most suitable tool to measure the environmental impacts, one of the sustainability dimensions, since it displays a clear view where the weaknesses are located within the chain (Barbosa-Póvoa et al., 2018).

By analyzing the results, it is possible to understand that, throughout the entire life cycle, exploited resources with a higher success rate balance out the ones with a lower success rate within the resource and production management of a certain product or service. The life cycle inventory analysis quantifies the energy and material consumption and emissions to air, land and water at all stages of the product structured life cycle (from raw material extraction to production and disposal). Finally, it calculates the physical inputs and outputs, and then summarizes them throughout the life cycle. LCA can identify the environmental impacts of a planned industrial symbiosis.

[1] An agricultural Cooperatives is a group whose members are small olive cooperatives and private olive growers of composting, food and pharmaceutical industries and materials for research companies. A cooperative is an independent partnership of individuals who voluntarily teamed up to meet their common economic, social, and cultural interests and ambitions through jointly owned and democratically controlled firms (COPAC, 2015).

The methodological framework for performing a life cycle assessment has been standardized by the International Organization for Standardization (ISO). The ISO 14040 standard describes the four stages of life cycle assessment: Goal and Scope (ISO 14041), Life Cycle Inventory (ISO 14041), Life Cycle Impact Assessment (ISO 14042), and Life Cycle Interpretation (ISO 14043). The following table (Table 5) exposes a LCA structure adapted from Huppes (2009).

Table 4- Life Cycle Assessment Methodology, adapted from Huppes (2009)

Life Cycle Assessment	
Goal Definition and Scope	Identify: the purpose of the study, the functional unit (Olive Oil's Supply Chain), system boundaries (can be determined by the lack of significant data about some processes of the chain), the measure of performance, general assumption, scenarios, study time horizon.
Life cycle inventory analysis	Quantify the material and energy consumption (life cycle aggregated physical outputs and inputs), including emissions to air, land and water for every stage of the life cycle of a product.
Impact assessment	Aggregate meaningful and consistent data to construct an explicit value system, in order to robustly evaluate the options or to generate better ones.
Results interpretation and improvement assessment	After converting partial value units into overall value units by assorting weights to each category analyzed, results are comparable, especially when different parts of the system are being assessed. Suggest possible actions for future environmental enhancements.

3.2.4 Industrial Symbiosis (IS)

This study uses an analytical framework to successfully transform today's linear economy into a circular economy accelerating the transition from wasteful to closed-loop systems, while maintaining or increasing economic competitiveness, sustainability, resource efficiency, and resource security (Abreu & Ceglia, 2018). IS is currently classified as a subfield of industrial ecology (IE), that is translated into a complex cross-industry collaboration between economically independent stakeholders, aiming to achieve collective benefits (Yeo et al., 2019). Companies collaborate to achieve mutual goals, in a context where cooperation and synergistic opportunities should be integrated when developing processes or products which account for divided investment costs, diversifying risks, information exchange, shared knowledge, and collective decision-making from all parties (Herczeg et al., 2018). The IS-oriented SC aims to effectively coordinate the supply and demand of by-products while creating a sustainable collaborative system. So, according to Nazli Turken (2020):

"A symbiotic supply chain is a network of traditional and symbiotic suppliers, manufacturers, distributors, customers, and logistics, marketing, and related systems with the dual goal of achieving customer satisfaction through offerings of value-adding products, by-products, and waste, and minimizing non-product output disposal and improving resource efficiency."

Traditional SC and Circular Symbiotic Supply Chains (CSSC) differ from one another in numerous aspects. A CSSC besides being composed of raw material suppliers, manufacturers, retailers, and consumers as a standard SC, also includes other intervinients such as, symbiotic suppliers, symbiotic distributors, symbiotic collectors, symbiotic buyers and IS promoters. Another relevant difference is that in an IS relationship, one's non-product parts (e.g. industry waste/ by-products) or excess utilities will be another's production cycle input, this may cause uncertainty in terms of the diversity of the retrieved materials. Also, a traditional SC strives to add value, meet customer needs, and maximize profitability, whereas a CSSC besides that also seeks to minimize the non-product parts that are going to be rejected and improve resource efficiency in the manufacturing phase (Turken & Geda, 2020). For an efficient flow of materials, matters such as geographic, institutional, social, organizational, and interaction proximity can help promote the IS relationships. The proximity between companies is considered an important factor, as producers tend to build up storage on waste biomass (bulk), it reduces the cost of participating in supplies and transport. Globalization can also have the opposite effect, reducing such interactions within local communities. A closed economy can lead to a return to localization (Abreu & Ceglia, 2018).

EU Directive (2008/ 98/ EC) calls on State Members to focus on recycling waste and by-products. The Commission is currently focusing on restructuring regulation to facilitate the trade of by-products aiming to trigger a long-term culture ecology oriented proactive industries, as part of an action plan for its Circular Economy (European Commission, 2018). Economically, we are used to thinking of different companies in the same market, commonly as individuals competing with each other. However, that reality will have to be dismissed among new cooperative alliances that have to combine forces to take advantage of each other's capabilities for a higher general understanding of environmental issues, although traditional competition will continue to exist alongside. Setting up an IS initiative is not easy, for example, the Expected Return on Investment (ROI) is lower than the typically required rate of return for a stakeholder to embark on an IS relationship project. For this reason, companies heavily rely on financial incentives from public agencies or private equity investors. These include payment mechanisms to beneficiaries (mitigation subsidies, carbon credit markets, low-interest loans) for initial investments related to the introduction of more efficient practices (FAO, 2016), or payment mechanisms to polluters to induce the introduction of damage reduction technologies/ practices. Fees and taxes for pollution according to the amount, the environmental costs are assumed as internal and should be accounted for when decision making concerning production is being made. Without such governmental incentives, or in the case of long payback periods, companies may be reluctant to participate (Herczeg et al., 2018). Besides funding, it is necessary to promote legislative pressures that contribute to the further development of inter-company networks and cooperation. Economic incentives alone are not sufficient to normalize industrial ecology. Present manufacturing systems are designed to maximize direct benefits for producers and consumers of individual products, rather than for the sake of the community. Briefly, policies have to be stable and long-term so that investors from the private sector have the confidence to invest (Frosch & Gallopoulos, 1989).

Additional costs and coordination for by-product processing, storage, and delivery can be one of the reasons companies may reject the idea of turning to IS, nevertheless, such measures can help pay for processing or disposal. Suppliers' and buyers' core business is not trading by-products, IS relationships are different from traditional supply chain relationships, yet the majority of companies financially benefit from retrieving cheaper supply materials or avoiding disposal costs and generating additional profit from by-products sales (Turken & Geda, 2020). At times, IS companies equally rely upon each other, which means that companies are generally logistically and strategically in synchronization and ultimately share mutual risks and benefits on one or more operations. In contrast, companies are not always equally dependent on each other, leading to unbalanced involvement. If the waste or by-products supply (or demand) happens in crucial primary production activities, it is important to increase resilience by anticipating the occurrence of certain events, for example, a shortage or partner withdrawal, among others. For instance, the availability of industrial waste is the result of a push process, meaning that surplus or shortage can occur due to the variability in supply and demand, and the different seasonal characteristics in different industries (Herczeg et al., 2018). The risk can be mitigated by involving multiple buyers (or suppliers) or even signing a supply-demand agreement. In order to address the surplus and shortage of IS, since waste oil and biomass deteriorate, it may be necessary to store industrial waste according to its lifespan. After the expiration date, the excessive waste may need to be disposed of; Additional original raw materials may need to be purchased; A limited amount of waste may need to be allocated to several interested buyers. Technical issues, such as storage space and equipment connectivity, as well as operational issues such as inventory management, purchasing raw materials, and using multiple material sources for production planning.

An IS network (ISN) integrates the set of enterprises that interrelate through a symbiotic relationship, requiring at least three entities to interact. Hence, an ISN differs from an SSC, since an IS network may cover an entire SC, as well as the SSC may not be representative of the total IS network design (Fraccascia & Yazan, 2018a). In order for these exceptional relationships to be managed efficiently, it may be necessary to integrate a facilitator member between the two, denominated IS promoters (Abreu & Ceglia, 2018). Figure 13 describes the role of IS in accordance with state authorities, implementing initiatives focused on recycling and creating a market for recycled materials, promoting the transition from the traditional linear economy to CE.

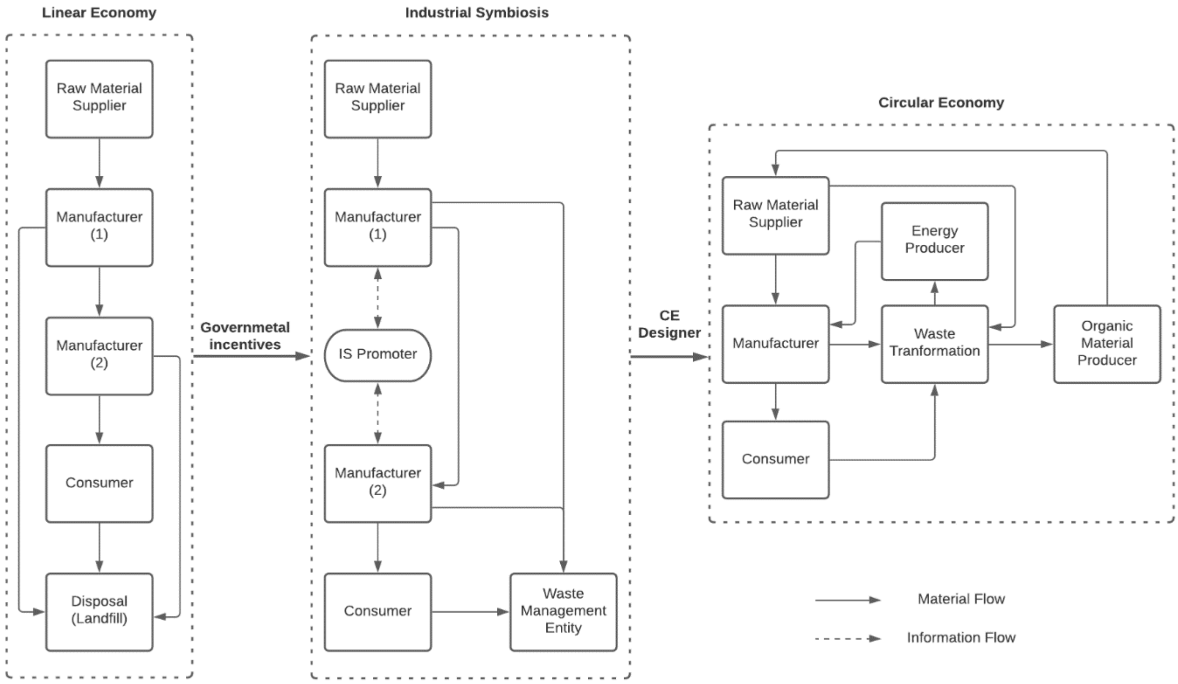


Figure 18- Schematic figure on the transformation from a linear economy to a circular economy by means of industrial symbiosis, adapted from Abreu & Ceglia (2018)

3.3 Chapter Conclusions

In this chapter several important concepts were dealt, in terms of supply chain structure and network design, regarding industrial symbiosis initiative. The characteristics of a Circular Economy system, Waste and by product, Bioeconomy, Closed Loop Supply Chain, Industrial Symbiosis were discussed in more detail for solving the case-study problem. The decisions that must be considered when designing this type of network were also enumerated.

Industrial symbiosis of a sustainable supply chain is a relatively recent subject in the literature, so research in this area is scarce. Literature on Industrial Symbiosis is expected to continuously increase in future years. The importance of Supply Chain Management will be highlighted in the next chapter, where it is expected that sustainable practices will be incorporated into all levels of the chain through the emergence of multiple symbiotic relationships, by actively encouraging the major players to remove barriers that are still on the way of establishing these relationships. Hopping that as a result, the entities involved in the process of delivering a specific product to the end consumers are better equipped to play a critical role in sustainable development, both in the direct and indirect SC.

4. Case Study Development and Methodological Approach

4.1 Methodological Approach Structure

This case study is an exploratory case study, based on existing literature. This chapter aims to structure the methodological approach followed next, based on previously highlighted challenges. Earlier studies have presented drivers that support the introduction of new IS relationships in order to support CE, as well as common barriers that hinder its establishment. These steps can be described as follow (Figure 19):

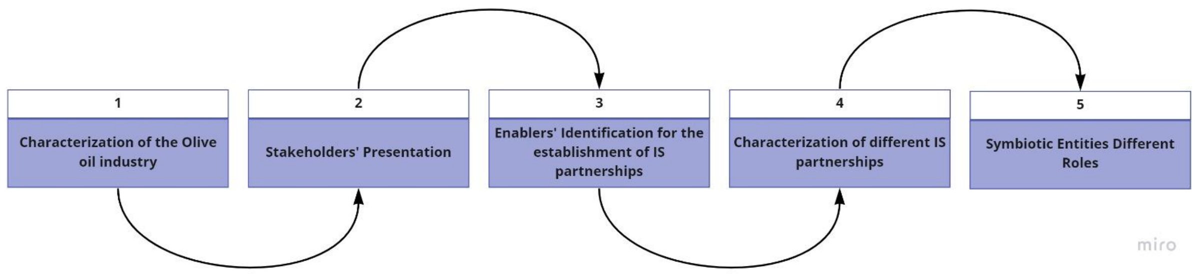


Figure 19- Supply Chain Symbiotic Relationships Characterization Methodology

1. Characterization of the Olive oil industry: characterization of the industry and its current position in the market. Classification of the system's outputs and their respective destination. Clarification of the motivation and the work's purpose.
2. Key Players Presentation: description of the stakeholders present in different stages of the Supply Chain, directly and indirectly.
3. Enablers acknowledgment for the development of IS relationships.
4. Characterization of different IS partnerships: extensive understanding of the set of possibilities for establishing IS relationships along the chain for waste management purposes.
5. Key Players Roles: Understand the context and distinguish which entities are involved, both in a traditional logistics management and waste management perspective. Secondly, present each individual's role taken in the chain, as well as the level of the chain in which they are involved along with their major concerns.

The research presented below may be applied whenever a particular entity wishes to identify possible collaborative improvements in a given SC, regardless of the reasons (academic research, optimization of relationships management, sustainability concerns, among others).

The identification of barriers, critical points and recommendations to establish IS relationships in a chain, was highly influenced by the following authors: Luthra et al. (2022), Fraccascia &

Yazan (2018b), Kosmol et al. (2021), Bacudio et al. (2016), Albino et al. (2016), Agudo et al. (2022), Fahmy et al. (2021), Simangunsong et al. (2012), Kuznetsova et al. (2017), Abreu & Ceglia (2018), Donner et al. (2020), Moktadir et al. (2018), Tura et al. (2019), Taddeo (2016), Al-Tabbaa et al. (2019), Mastos et al. (2021). The following framework was followed (Figure 20):

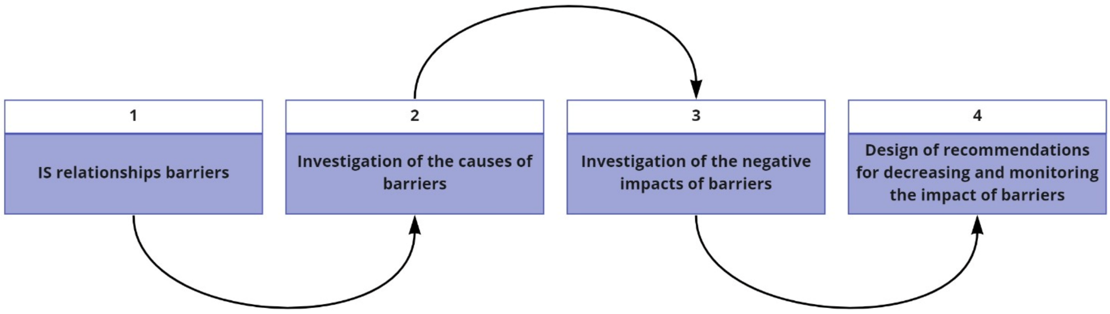


Figure 20- Barriers Identification Framework

1. Barriers Identification: relevant barriers to the establishment of IS SC relationships will be exposed.
2. Investigation of the causes of barriers: gathering relevant causes for emerging barriers when establishing IS SC relationships.
3. Investigation of the negative impacts of identified barriers: considering relevant scenarios for the case study, which will stress possible benefits or inconveniences.
4. Overcoming barriers: several solutions will be suggested. Also, it aims to identify several points that will guide partnership beginners on how to grow these relationships and measure their partnership benefits.

4.2 Supply Chain Symbiotic Relationships' Barriers Approach

This chapter is aimed at defining symbiotic relationships management from a collaborative perspective of SC aiming to minimize the environmental impact. It was divided into four different sections in order to properly structure the case study. The first characterizes Olive Oil Supply Chain concerning each products source and respective end use, having in regard its final state and product characteristics. The following section exposes which are important stakeholders who may be capable of implementing change in the system under study, as well as their respective roles and major internal concerns in the third section. The fourth and last section is divided into seven subsections, compromising an overview of the most limitative barriers for establishing and maintaining multi-sided collaborations within the SC, referring to: lack of trust and commitment, distinct beliefs, intensified risk and uncertainty, operational and economic differences, level of skills and technology, governmental restraints and added complexity and responsibility. This arises from the objective of this work and combining this motivation with the information presented in the previous chapters.

4.2.1 Characterization of Olive Oil Supply Chain

Portugal has excellent soil and climatic conditions for the cultivation of olive groves. Olive trees have become an integral part of the Portuguese landscape, with olive oil appearing in almost every traditional gastronomy. Portugal is a major producer and exporter of olive oil in recent years. The olive grove area is concentrated in approximately 2,000 farms, with an average area of more than 20 ha, reflecting, among other things, the sector's dynamism, technological progress, and improved management, which benefits from economies of scale and optimized exploitation value (David Catita et al. 2021).

According to the Portuguese Classification of Economic Activities, Revision 3 (CAE - Rev. 3), olive oil production is included in Section C, which is part of the PRODUCTION OF OILS AND FATS, Division 1041. This activity has increased significantly, owing to an increase in olive production, the introduction of varieties with higher industrial yields, the adoption of new, more intensive technologies with lower production costs for the installation of mills with increasingly modern extraction technology, and a situation revealing more market-oriented business dynamics. In Alentejo region, modernization of the sector allowed for a 1.17-fold increase in olive grove area between 1998 and 2015, resulting in a seven-fold increase in regional olive oil production. Portugal has been self-sufficient in olive oil since 2014, accounting for 3.4 % of global production (GPP/INE data, 2017).

Motivation: In Portugal, approximately one million tons of olives are processed per agricultural campaign year, which operates seasonally from November to February, with an increasing trend. Resulting in large quantities of olive pomace, the disposal of which is obliged by law. In order to prevent the buildup of potentially harmful material to the environment. A greater variety of processes and recovery locations is emerging, in order to not jeopardize the normal operation of mills, particularly during the olive oil production season. The economic benefit of all firms is increased in the case of industrial symbiosis compared with its absence. Furthermore, total SC expenses in an integrated supply chain are lower than in a supply network handled by independent efforts.

Figure 21 is intended to illustrate the relationship between the classification of outputs from different olive oil production activities, such as: olives production olive oil manufacturing, and olive oil commercialization; with the treatment or destination granted to the output. It should be noted that the main identified residues produced by this process are water mills and **olive pomace,** the latter being the focus of the study, formed by the remains of crushed olive pulp and lump.

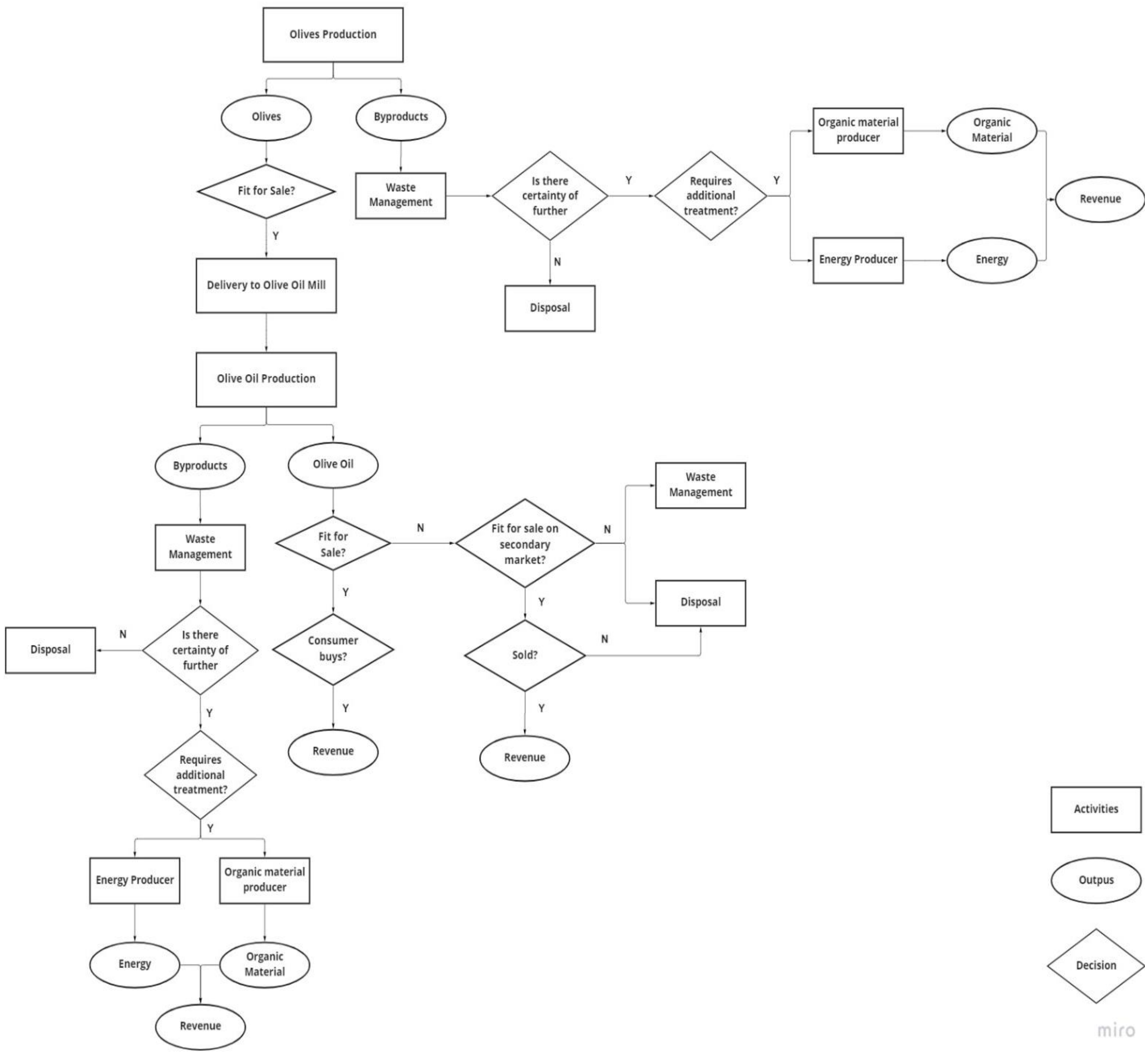


Figure 21- Illustration of Olive Oil's Supply Chain Destinations

The primary resource flow is the onward flow of products, whereas secondary resource flows are goods that are recycled, retained, or reused (Luthra et al., 2022). The following chapter indicates key players involved in both primary resource flow and secondary resource flow, that will perform a decisive role in developing IS relationships and contribute to performing the activities seen above.

4.2.2 Key Players in the Olive Oil Industry

With the purpose of achieving widespread use of sustainable value chains, business models must be developed in parallel that can be replicated and adapted to an optimized variety of locations and contexts, preferentially with a lower level of investment, risk, and technical sophistication required to establish value chains for food and bio-based products or promotion of new alternatives, taking advantage of each site (availability of resources, socio-economic factors, etc.) These models operating at the local/regional level will more easily enable circular approaches between SC intervenients (European Commission, 2018).

It is also necessary to develop innovative organizational models to encourage internal and external cooperation within the industry, small-to-medium scale solutions seem to be the most suitable. Characterizing the relationships created between the entities in the studied context is a crucial initial step in subsequently enhancing the partnership as a whole. In this context, it was developed a list of stakeholders, guided by the idea of stakeholder inclusivity, includes those persons and entities who, in turn, will influence the capacity to accomplish the study objectives or conduct the study. A wide range of actors need to get involved in cooperative actions: (i) food farmers; (ii) food manufacturers; (iii) local commerce- retail and local consumers; (iv) waste management companies- by-products transformation facilities; (v) community and educational institutions; (vi) regulatory bodies and government agencies; (vii) environmental associations and investigation centers; (iv) leaders of the industrial and financial community (EMF, 2019).

It is important to mention that all actions related to the olive oil sector, whether through information sharing or fostering institutional dialogue with the government and other institutions involved in economic, financial, social, and political areas are carried out through the various organizations that represent our industry, namely:

- *BCSD - Conselho Empresarial para o Desenvolvimento Sustentável.*
- *Casa do Azeite de Portugal.*
- *CEPAAL - Centro de Estudos e Promoção do Azeite do Alentejo*

The following table enumerates some of the actions that should be taken by the agri-food-waste system's stakeholders:

Table 5- System's Stakeholders, adapted from EMF (2019)

Actors	Activities
Food Farmers 	- Optimize cultivation, harvesting, transportation operations, in the sense of reducing energy used and generated waste. - Choose organic fertilizers rather than chemical fertilizers. - Redesign operations, as to include waste management operations.
Food Manufacturers 	- Use Marketing to influence to increase recognition of circular products. - Whenever possible use innovative food by products as raw materials. - Ensure product's quality and security. - Create sustainability certification labels. - Redesign operations, as to include waste management operations.
Retailers or Customers 	- Prioritize purchasing products to regenerative food producers. - Ally with programmes such as "*Too Good To Go*", "*Ugly Fruit*", in order to reduce waste. - Optimize logistics network through reliable forecasts (demand ≅ supply); centralize information for redistribution purposes.
Waste Management Companies 	- Define local Collection Centers. - Develop Reverse logistics network. - Partnership with public and non- public sector actors to use food by-products to create valuable bio-economic products. - Implement wastewater treatment systems for olive oil mills.
Local communities 	- Engage consumers to make informed decisions (sustainability certification labels). - Educate communities, for responsible consumption and conscient waste disposal.
Regulatory Bodies 	- Introduce beneficiary policies and funding programmes for those who embrace CE actions. - Contribute with advanced technologies and infrastructures - Guidance, support and regulatory compliance and enforcement

Investigation Centers (universities, private or public owned laboratories, environmental associations) 	- Establish partnerships with organizations, the government or even NGOs, for whom research in this field is of high importance. - Propose future research directions that are innovative, aiming to shift to a circular system.

CE strategy seeks to engage and enhance these types of businesses' links to the value chain, since they play an important role in producing additional value from waste while sending materials and energy back into the supply chain. Characterizing the relationships that can be established between the entities in the examined scenario is a vital initial step towards subsequently enhancing a CSSC. Moreover, the outputs of the synergy and the specific objectives of the actors engaged to define the synergy's paradigm, whether mutualistic or commensal. Mutualism can be recognized, for example, when all symbionts (IS participant partners) obviously benefit from synergy. When a company voluntarily contributes a certain resource output to another organization as an input, the resource receiver receives the full benefit of the synergy (commensalism) (Jensen et al., 2011).

The **first** step is to acknowledge that you want to participate in the development of a symbiotic network. What will push companies to pursue integration with one another is the idea that it will increase SC efficiency as a whole while being secure that the single company's performance will still be maintained. At least three distinct enterprises must interconnect and collaborate in order to exchange at least two different resources before they can be recognized as part of an Industrial symbiosis, said by Chertow (2007) and Albino et al. (2016). The 3 to 2 heuristic reveals the importance of dealing with several players, creating a complex system as opposed to a direct one-way transaction. Symbiotic networks will contribute to decreasing private costs and promote private returns likewise common linear relationships but will also represent a great advantage to the production of public environmental benefits, resulting in one of the most distinguishing features of industrial symbiosis (Chertow, 2012).

An industrial ecosystem can evolve in this model as a result of decisions made by private agents who are economically motivated to exchange resources in order to achieve goals such as cost reduction, revenue increase, or business development (Chertow & Ehrenfeld, 2012). Such partnerships leverage partners' abilities and resources to achieve common goals such as improving environmental results, restoring the environment, boosting the company's reputation in the market, and obtaining credibility in the eyes of relevant parties.

Potential Enablers

We will experience ecological scarcity of resources with potentially permanent environmental repercussions if sustainable manufacturing techniques are not embraced in emerging nations (Moktadir et al., 2018). Implementing an ISNs while relying on CE techniques will allow reducing the need for chemical fertilizers applied to crops, plus reducing the need for non-renewable energy sources, and even promote organic enrichment and improvement of soil structure contributes to reducing the amount of water required due to induced soil retention capacity thanks to organic fertilizers application. Eliminating a potential source of pollution, and creating value where previously was a cost are some of the examples of an ecological enabler of establishing IS (David Catita, et al. 2021). The food industry is a very competitive economic environment and fast passed. To maintain their competitive edge, the olive oil production businesses should take efforts to develop a sustainable manufacturing environment. The pressure from competitors to go green may be a major driver of sustainable manufacturing production processes. Customer attention to environmental sustainability can force industries to embrace sustainable strategies. Customers are increasingly choosing environmentally friendly items as a result of information from the government or increased public awareness (EMF, 2015). Another way regional, municipal, and even local governments assist is by operating as a link between legal authorities and enterprises. Legal authorities can reduce regulatory barriers and promote two-way discussion on the impact of legislation on IS, as well as provide conditions for faster government legal response. This is an essential attribute since they are aware of local conditions and contexts and may contribute to developing appropriate national policy. They have also been able to design more customized policies and promote emerging synergies as a result of this insight. For example, increasing the percentage of products that can be reclassified as non-waste.

The **second** step to establishing relationships is always networking, and here a theme emerges:

- Where can a company find a group of partners from diverse market sectors who are interested in behaving in accordance with circular economy beliefs, and together build a complex supply chain based on a network of high-confidence symbiotic relationships, such as service providers (e.g., transportation or storage) or suppliers?

Albino et al. (2016) quoted Dooley (1997), Holland (1995), Holland (2002) who stated that self-organized symbiotic relationships appear from spontaneous decisions made over time by self-driving but interrelated enterprises, with no entity or central control mechanism guiding or

regulating the whole system, like a deliberator organization or the state. In order to enhance their market fit which directly influences a company's performance, ISNs are the culmination of a series of existing self-organized symbiotic interactions. Chertow (2007) classified three different types of Industrial Symbiotic Systems according to distances between each other:
The first is known as eco-parks and is recognized as the "classic" inter-firm relationship between enterprises placed adjacent to one other inside a designated common space. The second type is an inter-firm cross-network of enterprises with symbiotic relationships that are located within the same region but do not share the same area as the first. The third type are firms that collaborate across wider distances. Albino et al. (2016) have proposed a contractual structure that encourages corporations to engage more spontaneously, in a self-organized model.

On the other hand, when there is a central authority controlling the supply chain as a whole, cross-ventures between various and independent enterprises are more likely to arise. It is difficult for businesses to define objectives without considering their best interests, Cachon (2003) believes that this central authority must be accountable for ensuring that these established collaborations do not affect one's primary company. Once there is a central authority entirely managing the network, cross-ventures between various and independent enterprises are more likely to arise (Albino et al., 2016).

The presence of an intermediary entity can be necessary in order to accelerate the process of establishing possible symbiotic connections. This intermediary may offer administrative and regulatory assistance, help to pursue incentive policies, and share their expertise with businesses at the initial stage of a system. They can be present in several forms, for instance, as a contract, as a facilitator who looks for eventual optimal matches through a set of options or simply as knowledge agents (e.g, through a procurement platform where different individuals can gather and exchange ideas on different topics) (Capelleveen et al., 2018; Freitas & Magrini, 2017; Notarnicola et al., 2016). Furthermore, they operate as a knowledge channel across industrial clusters, as mediating "neutral participants," they promote interaction and collaboration among stakeholders with differing and often divergent ideas and share their lessons learned from past experiences.

Either way, the desired outcome is for the parties involved in the exchange to share mutual benefits and extend the diffusion of ISNs to new sectors, where the cooperative exchange of resources is not currently happening in a symbiotic and consistent way.

After procuring, the **third** step is choosing a partner from a pool of potential companions may be a difficult undertaking. It is crucial to collect information on the characteristics of partners: industry, size, acknowledgment of the circularity strategic value, waste categorization and quantification, waste recovery policies, waste value chain- reintroduction in another chain, and awareness of the ecosystem concept. Again, the selection of symbiotic partners is not an easy task, since it is more idealized rather than realistic, because some partners may not want to form a symbiotic network. Aside from selection, the appropriate number of partners must be defined, because of the more diverse and larger the number of optimal, willing, and stable partners, the better the firm's symbiotic readiness (Agudo et al., 2022). Readiness is defined as the propensity of a company to be willing to adopt a *symbiotic behavior* with the selected allies based on a circular economy standpoint, this is an adaptation of the definition given by Agudo et al. (2022).

The next section will clarify the role of each stakeholder both in the direct resource flow and in the byproduct resource flow.

4.2.3 Symbiotic Entities Different Roles

After describing the system's stakeholders, it's essential to map what role each one of them plays, how they interact, and what their concerns are. This scheme assumes that each level of the SC is simply represented by just one entity (Figure 21).

Olive farmers provide their finished product directly to olive mills. Price changes in raw materials and energy will have an immediate impact on sales margins and market prices for customers. If these price fluctuations occur in a generalized manner, they may not pose a risk to the SC; nevertheless, if they occur at the level of a specific niche, they may indicate a competitive disadvantage. If companies are not properly aligned with one another, their production and distribution capacities may not be properly dimensioned (Lutthra, 2022). Distribution services will be required by the olive oil producing firm to carry its manufactured products, olive oil and olive pomace, to retailers or recycling and recovery facilities. The producer can construct its own distribution network, which will be more expensive and difficult in the short term but can provide a competitive advantage in the long-term. In addition, rather than creating its own distribution network, the manufacturer can simply use third-party logistics services and focus on its primary business. Following the direct SC, retailers will sell the olive oil to end consumers. It is a more sensitive operation since it is directly linked to the consumer. This side of the chain is distinguished by the need to provide a positive experience to customers through service quality, product quantity, and price, among other attributes. While the producer acts as a major resource provider for the olive pomace transformation entity in the byproduct distribution chain. It is possible to conclude that the treatment entity shares the same concerns as the olive oil producer, only with the added challenge that it will be highly dependent on the levels of olive oil production and the seasonality associated with it, potentially posing a constraint.

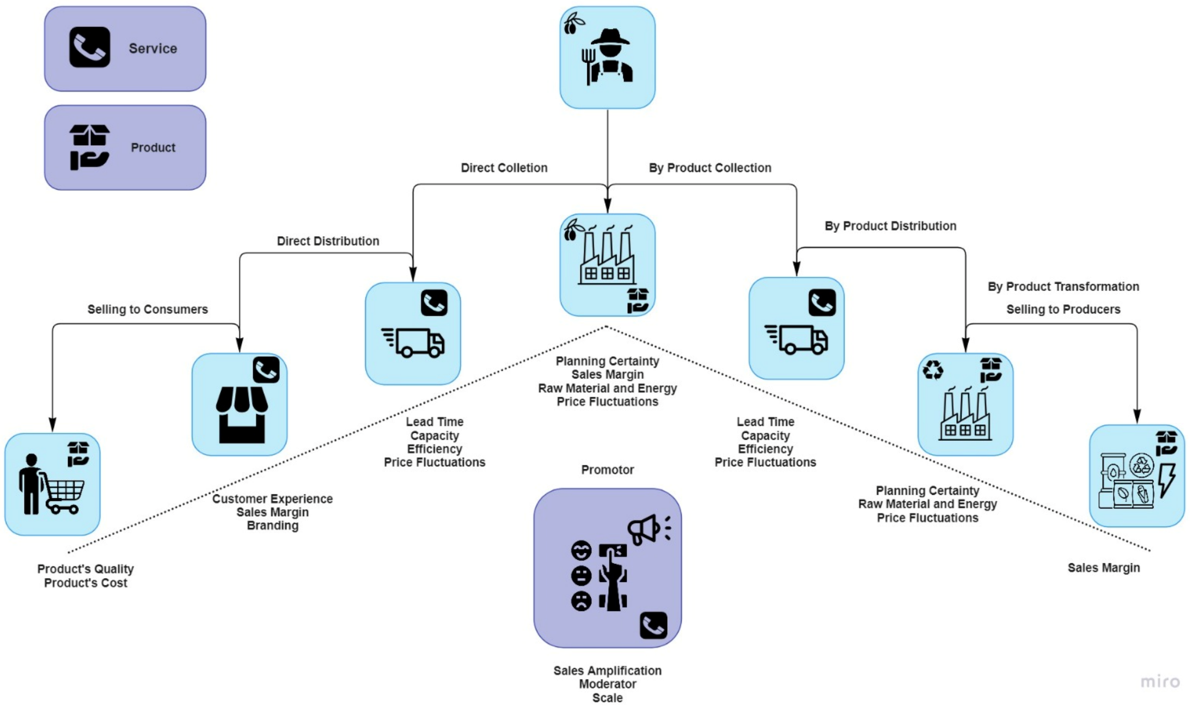


Figure 22- Olive Oil and Byproduct SC entities and major concerns

Taking into account the fundamental problems mentioned above, next, we will attempt to determine what are the most significant barriers to developing or maintaining SC symbiotic relationships. On the one side, a particular aspect may be a driver, while on the other, it may be an obstacle. Its impact is determined by the context and how it is controlled. We will focus on these points next.

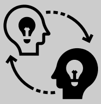
4.2.4 Identification of barriers in symbiotic relationships

After conducting a macro-research, it became noticeable that building and maintaining IS networks is still a developing issue. Namely, the existing studies are mostly concerned with showcasing the positive effects of such collaborations, rather than exposing what needs to be done to close the existing gap in establishing/maintaining newly formed bonds between cross-sector entities while dealing with the complexity and uncertainty of supply chains. To this day, there is no defined guidance that assists in the improvement of the collaborative system so that core activities and the company's longevity are not to be jeopardized (Prima Dania et al., 2018).

According to Tan, Andiappan, Wan, Ng, and Ng (2016, p. 46) citing Jackson and Clift (1998), every business is a "self-motivated maximizer of individual profit" who may or may not be interested in maximizing the advantages for the overall system, the difficulty is to identify a reasonable and just distribution of the benefits among the partners. This issue should be pointed out as a threat to guarantee the relationship’s sustenance in the long term. The next steps in this case study will involve identifying potential relationship weaknesses, recognizing the barriers that remain unanswered to this day, and devising several tactics to overcome them. Some of these barriers must be eliminated within top management of individual companies, while others must be addressed between organizations; in these cases, third parties contracts are frequently used to offer strength and to break down barriers (Maqbool et al., 2019).

This chapter was heavily influenced by Luthra et al. (2022) paper. The referenced study assesses in general terms the challenges of cross-sector partnerships within supply chains plus proposing a strategic roadmap to bridge the existing gap. It contributes in a variety of ways by elucidating collaboration among cross-sector players and emphasizing the need for resource optimization thru waste management. The barriers recognized by the author are the following ones (Table 6):

Table 6- Industrial Symbiosis Barriers and a brief description

Barriers	Description
 **Lack of Trust and Commitment**	Trust is fundamental. Without it, a good cooperation, a predictable behavior between partners, better coordination are not possible. Trust is directly correlated with the probability of maintaining a relationship. There will always exist different levels of dependency between partners, what can lead to unengaged leaders, which may include lack of willingness to collaborate.
 **Distinct beliefs**	Each company is embedded in a singular institutional culture, whereas partners may be reluctant to make the transition from the existing vision to a common one.
 **Risk and Uncertainty**	What was once one's risk, will now become a diffused risk throughout all concerned stakeholders. Firms are vulnerable in environments characterized by diverse levels of uncertainty.
 **Economic and operational**	Creating several IS relationships means managing different geographical operations, leading with various growth strategies, adapting to supply fluctuations, and many other circumstances that may come up, impacting the company.
 **Level of Technology and Skills**	The level of technology varies from entity to entity, it may be due to a lack of budget to invest in technology or simply because they do not believe it will improve the performance of the company/chain. In fact, not owning the right technology to implement more sustainable operations poses a restraint for the sake of the company's progress towards a more ecological future. Limited knowledge on the topic can cause resistance to embracing change in an organization. IS implementation demands expertise in a variety of domains, including technical and organizational understanding.
 **Government regulations**	It is important to ensure that, despite any changes to the management structure, a company will continue to respect every legal obligation. Exchanges can be particularly problematic if still these cannot legally be exchanged.
 **Complexity/Responsibility**	Complexity is assumed to be the amount of effort required to implement fundamental changes in operations, from a single synergy relationship to numerous. Also, each company's responsibility is correlated with the number and complexity of operations performed, which will exponentially increase.

4.2.4.1 Lack of Trust and Commitment

Trust for many organizations is problematic where competition is the norm (Taddeo, 2016). Though, companies with the capacity to adopt IS are usually positioned in distinct industry sectors that do not really compete directly for the same markets. So, potential IS partners should be treated as 'friends,' and win-win strategies for all should be embraced (Fraccascia & Yazan, 2018b).

When starting new partnerships, the level of trust in other partners is expected to be low or non-existent. Trust is a prerequisite of collaboration since most stakeholders have minimal or no prior cooperative mechanism in the form that is required for IS (Bacudio et al., 2016). The level of trust will highly influence the potential outcomes of any partnership. According to Albino et al. (2016): *“The level of trust is modelled as the probability of each firm making decisions that are not detrimental to the other party (...) The higher the probability that the firms maintain mutual beneficial relationship, the higher the level of trust in the relationship. Thus, we define TRUST as the probability of maintaining the relationship, while (1-TRUST) is probability of seeking a new partner”.*

Cooperation and trust are a basis for a predictable behavior between partners, joint agreements, better coordination, and alignment. In other words, the ability to cooperate can be assessed on the basis of a competitive situation of potential partners. If competing companies were involved in the same synergy, the collaboration's 'true spirit' can be disturbed producing friction among different parties and eventually leading to less trust and ability to cooperate, which may lead to failure (Kosmol et al., 2021).

Companies can reach to an agreement and collaborate with each other, but if companies’ interests do not match, or the distribution of resources and benefits is uneven, or if they are not equally engaged in bringing optimal impact, individuals can become misaligned (Bacudio et al., 2016). If a company's established relationships aren't critical to its primary activity or to enhance its market position, its level of commitment will be lower than that of a company that fully devotes itself to the relationship because the company's existence is largely dependent on these relationships. However, familiarity, strong social ties, and common standards across enterprises successfully consolidate IS relationships reaching a significant level of trust is accomplished between cross-sector collaborations, it tends to limit firms’ opportunistic behavior (Jensen et al., 2011). Thus, trust determines the behavior of enterprises that are linked in a mutually advantageous symbiotic connection. Even though, in the initial stages of a relationship is more probably for one or more partners may opt to end the relationship in order to pursue more productive connections. In fact, even if the partnership is mutually advantageous, one of the parties might always seek out a new symbiotic partner with whom the mutual benefit could be maximized (Albino et al., 2016).

Concerns about losing control over their operations sometimes may discourage organizations from entering into connections ISNs. The level of transparency and poor quality of disclosures between different sectors is directly correlated with the level of trust companies have in each other. Typically, top management is unsure what information can be shared to facilitate CSCM cooperation and care about data loss (Luthra et al., 2022). Communication amongst possible key stakeholders is critical for promoting the synergy's beginning and maintenance. Supposably, exchanging pertinent data is done through communication. Information concerning such as company capabilities, goods, customers and costs/sales, staff information, raw materials, volume of waste and its flow, energy consumption, the ecosystem, manufacturing systems, and strategies (Agudo et al., 2022; Belaud et al., 2019). The availability and quality of data frameworks and proper channels of the communication might result in reduced uncertainty and better rollout negotiations (Kosmol et al., 2021). It's crucial that companies together, can recognize which key data should be communicated and how to manage information flows between distinct partnerships. For example, providing non-sensitive information about geographical areas and volumes has a lower positive effect than sharing sensitive information about costs when measuring performance metrics (Fraccascia et al., 2018).

Recommended Solutions

Fraccascia et al. (2018), suggested that for a successful ISN implementation both waste producers and waste treaters should provide data to an online platform. This platform would allow for information input to be filtered through computations, from one entity to the other along the network, if a company considers a certain type of data to be sensitive and not to be shared with others. Indeed, the online platform under investigation in this paper serves as an IS' facilitator. As a result, they don't reveal their information to one another, but rather to the platform, which automatically controls the best cooperation strategies. Nevertheless, every company must fully trust in the facilitator in order for the facilitator, in this case, the online platform, to collect information.

Moreover, if an IS partnership is disrupted, companies may use an online platform to select a suitable symbiotic partner more readily and rapidly, lowering transaction costs associated with the search and mitigating consequences through the chain.

The first step should be to determine whether the various pieces of essential information from multiple sources are compatible. The second step is to evaluate the fundamental data-modeling architecture of IT tools for information exchange that are more suitable for IS collaborations. At a high level, ISO 8000 is intended to motivate businesses to request data from their data providers, while ensuring that data is interchanged between applications without losing core information. ISO 8000 promotes data quality compliance. It is impossible to have quality information without quality data, and the other way around. The third step is to specify how and who may use the tool (Maqbool et al., 2019). When technology, processes, and information are exchanged data integrity and cybersecurity must be preserved in order to consolidate partnerships through time (Luthra et al., 2022). According, if a company wants its information to be managed according to high management and security standards at the level of Information Security, it should ensure that its clients, partners, and suppliers have ISO 27001 certification, which means that the company was examined by an external and suitable entity.

Another good strategy to enhance the level of trust is proposed by Albino et al., (2016), that advise companies on how to build a proper contract, by aligning the benefits of both parties involved in the exchange and addressing confidentiality terms on information sharing. This will most certainly maximize the number of stable IS relationships, one of the system's aspirations, which ultimately stimulates the creation of a stable ISN connections.

Bellow, it is possible to visualize how the level of trust will directly influence the level of information shared between individuals.

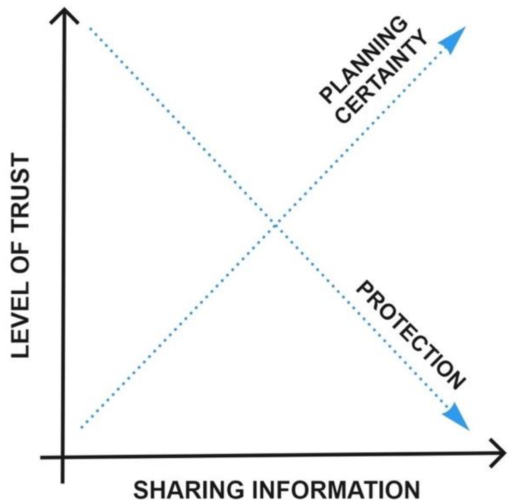


Figure 23- Level of Trust and Information Sharing Relation

Planning Certainty is identified as a key economic aspect in decision-making, which includes predictability and awareness of future developments, whilst helping to reduce variability in the supply chain (e.g., fluctuations in production volumes and prices or storage and transformation capacities). So, information may be used to determine how reliable a synergy's planning is (Kosmol et al., 2021). As previously studied, when the level of trust is directly correlated with the level of transparency, and hence with the magnitude of information made available to partners. As consequence, if the level of trust in a partnership is low, and simultaneously, the level of shared information is high, the tendency is for the company to feel under protected, as it is shown in Figure 23.

Furthermore, the expected stability of a system is important for predicting variations and determining whether they can be managed without causing significant economic and environmental damage (Kosmol et al., 2021).

4.2.4.2 Distinct Beliefs

Each company has its own autonomous planning and management procedures. The wider the geographical distance between each company's headquarters, the greater the disparities in mentalities will be. Most researchers suggest close proximity relationships, not only due to distribution costs, that are highly influenced by physical distance but also due to short mental distance. Enterprises with extensive backgrounds and stable environments have a stronger aversion to changing internal workflow.

Furthermore, there are differences in the compatibility of sectors, beginning with how companies monitor their performance. Due to the general lack of a common vision and policy framework, it may be difficult for organizations to develop a single policy across sectors and mutual vision within their business operations, models, and processes (Luthra et al., 2022). This fact alone already induces change management. On top of that, changing management to a more sustainable posture requires that everyone starts supporting activities connected to sustainable operations. The management strategy needs to be adapted because the linear approach of operating demands simpler management decisions – outputs are more or less linear, clear, and qualifiable/quantifiable – whereas the circular approach of operating results in non-linear and, in general, unpredictable consequences (Donner et al., 2020). Thus, making integrated planning toward Symbiotic Supply Chain Management extremely difficult.

Cross-sector alliances add complexity to the process of decision-making and create additional challenges for collective mutual action planning (Pittz & Adler, 2016). A multi-criterion model can be created so that decisions can be made in a logical manner, determining all of the decision makers' characteristics and interests, as well as their perspectives, requirements, and personal/collective goals (Fahmy et al., 2021).

Mintzberg (1979) associates decision-making methods with the phases of synergy implementation:

(i) Identification phase: identifies supply chain pain points (for example, sourcing materials price) and collects relevant data from each location side. In this regard, it's worth noting that defining the target is a challenging and crucial step in the method's implementation. Individual goals are unique and sometimes contradicting (Fahmy et al., 2021).

(ii) Development phase: identifies alternative problem solutions and possible impacts for each entity involved (i.e., range of affordable prices), whereas selection phase (Fahmy et al., 2021).

(iii) investigates and suggests the optimal solution. The extent to which the life cycle of processes and units is explored is left to the user. Similar system limits and life cycle stages should therefore be termed, to achieve comparable outcomes (Fahmy et al., 2021).

To choose the optimal option, evaluation objectives must be established ahead of time, describing the selection of criteria for implementing synergies and taking into account the interveners, that will perform the decision, and information needs. Also, a sensitivity analysis can be performed to look at how particular variations in ponderation coefficients affect not only the overall value of each alternative but also the final output of the model.

The decision-makers need to define target values and prioritize what must be in line with the overall partnership's best interests. This is, certainly, a challenging task not only because there are different beliefs, but also because of social and cultural disparities, which implies that concessions will have to take place, unavoidably, in both parties.

(Bichraoui et al., 2013) assumed through his model, that if plant managers exchange material through long periods of time, each partner would start to imitate cultural cooperation behavior. Hopefully, with time, companies will start to employ gradual passe IS and CE terminology on their own initiative after they become immersed in it. Nonetheless, this is a cultural change process (Abreu & Ceglia, 2018). Thus, homogenizing the way they communicate cultural values and beliefs through bridging intra- and inter-company obstacles.

4.2.4.3 Risk and Uncertainty

Uncertainty awareness was something that most of the IS related articles addressed, regarding discrepancies between demand and supply of by-products, timing, the quality with which the item arrives, transport modes, expansion of manufacturing facilities, collection points and distribution routes.

Simangunsong et al. (2012) summarized 14 different plausible causes of uncertainty, and grouped them into 3 major groups, internal organization uncertainty, internal supply chain uncertainty, and external supply chain uncertainty. And also made a research on what strategies could be used in order to reduce or control uncertainty, as follows (Table 7):

Table 7- IS Uncertainty Sources, Factors and Management Strategies

UNCERTAINTY SOURCES	UNCERTAINTY FACTORS DESCRIPTION	UNCERTAINTY MANAGEMENT STRATEGIES
INTERNAL ORGANIZATIONAL UNCERTAINTY	**Product characteristics**: including product features, packaging/transportation conditions, perishability or the product life cycle, and the level of product variety given, all of which can affect the order life cycle, in terms of time	Defining the right product's initial concept or redesigning the product to enable a better and more resilient production process.
	Manufacturing Processes: can affect order fulfillment/lead time which affects the whole chain. e.g.: Employer/ Machinery productivity	Making a process leaner simplifying it and reducing its inherent waste, use of resources and unpredictability. Improve company's staff, plant, and equipment flexibility allowing it to better deal with the uncertainty generated by fast changes on the shop floor, thereby increasing responsiveness.
	Control: manufacturing companies' capacity to receive costumer orders and transform it into a production plan.	Leaner Processes Shorter Planning Horizon Implement a production management support platform
	Decision Complexity	Decision-support systems are used to solve problems in complex decision-making scenarios.

	Organizational behavior issues: partners different profiles (e.g., risk averse versus risk seeker) and political influence.	Contractual agreements with suppliers or buyers to reduce uncertainty
	IT/IS complexity: even though it can answer some problems, it can also raise supply-chain vulnerabilities, as we have observed earlier in chapter 4.2.4.1.	Set boundaries in information sharing within an organization with the different chain partners, or via a regulated platform that ensures firm data security.
INTERNAL SUPPLY CHAIN UNCERTAINTY	**End Costumer Demand**: arises from fluctuations on demand or erroneous forecasts (Seasonal Demand/ Seasonal Production). Supply and demand may not coincide. In general, demand will moreover be stable, whereas supply is merely seasonal.	Improve company's staff, plant, equipment and distribution channel flexibility allowing it to better deal with the uncertainty generated by fast changes on the shop floor, thereby increasing responsiveness. Use stock security level to buffer against uncertainty Implement a marketing plan, trough pricing strategy to overcome unpredicted picks of demand
	Demand Amplification: is associated with bullwhip effect	Postponement Forecasting Simulation Mathematical modelling
	Supply: related with production processes and control systems suppliers' commitment rate. The greater commitment, the greater SC efficiency. Dimensions: timing, quality or availability of products	Set Stock Security Level Multiple Suppliers
	Parallel Collaboration: when a customer interacts with numerous suppliers, and one of them fails, this is known as parallel interaction. Eventually, the customer must obtain their product from another supplier. As a result, the whole SC performance suffers.	Detecting and reducing uncertainty using process performance metrics, including as quality metrics, key performance indicators (KPIs).

	Order Forecast Horizon: associated with planning certainty	Shorter period than the forecast horizon, thereby reducing the number of last-minute changes to the schedule.
	Chain Configuration/ Infrastructure and Facilities: e.g.: organizations locations, carriers' transportation capacities, Storage capacities	Redesign SC configuration and infrastructures of the network relationships Study operational variables and parameters (distances, capacities, input/output volumes) Outsourcing
EXTERNAL SUPPLY CHAIN UNCERTAINTY	**Environment (Sustainability)**	Implement performance indicators (KPIs) on environnemental dimension.
	Government Regulation, competitor behaviour and macroeconomic issues	Declassification of Waste Incentives and tax relief
	Natural Disasters	Purchasing insurance

Furthermore, diverse industries have their own distinct risk perception and mitigation strategies. Concerning risk, risk is already substantial when working alone, in a large integrated industrial system there is also the potential of risk escalating and hence systemic failure, particularly when a disruption occurs from outside the system (Kuznetsova et al., 2017). That is, risks that are difficult to control/ predict and can demonstrate the participants' adaptability along the chain. As a result, managing partners/collaborators from different industries can be tricky. Knowing that, olive harvesting is a seasonal activity that takes place from September to November, olive oil will need to be produced within a short period of time, in a way that preserves its sensory characteristics while also ensuring food's safety. Forecasting the annual demand curve for consumption will be necessary in order to create surpluses to answer the annual demand. Risk can be reduced by involving numerous buyers (or suppliers) or by entering into a supply-demand agreement. For example, in order to address the surplus or shortage of inputs/ outputs in certain circumstances in IS SC, since olive oil and olive pomace deteriorate over time, olive pomace more quickly than olive oil, it may be necessary to store industrial waste according to its lifespan, during which the product's characteristics remain unchanged and do not pose a threat to public safety, or to transform it per its demand.

ISO 31000:2009 establishes a framework for organizations to manage risk by recognizing it, analyzing it, and determining whether the risk needs to be altered through risk mitigation methods in order to meet their risk criteria. This entails analyzing potential risks and identifying operational prerequisites and critical points in order to ensure that risks are eliminated or effectively controlled. After assessing risks associated with industrial processes and realizing the key challenges that should be inputted in the system under evaluation, decision makers decide to follow one of the two different approaches for implementing the new optimized network: starting by reshaping on what already exists in order to complement the beneficial existing techniques (and eliminate harmful techniques), or else companies have to assume that they will have to redesign and replan the entire product chain. Since this standard is not industry or sector specific, it can be used by any entity: public, private, or community corporation, association, group, or individual. Forcing organizations to speak the same language when it comes to risk management.

4.2.4.4 Economic and Operational Infeasibility

Assessing possible financial returns and the resources required to achieve the expected return is a very challenging process, and normally it is one of the most important factors to consider when facing a decision. Since every business is a "self-motivated maximizer of individual profit" who may or may not be interested in maximizing the benefits for the overall network. Hence, the difficulty is to find a logical and fair distribution of benefits among the partners. Power and position asymmetry influence resource and benefit allocation (Bacudio et al., 2016). The main reason for this issue is poor management, for example, an uneven business size, such as small operators (in waste management) will intake significant economic risks when incurring considerable initial investment expenses, while a significant large company may incur less risk (Tura et al., 2019). Also, the time necessary for a return on initial investment (ROI) in this scenario may delay or impede the growth of an IS network (Taddeo, 2016). Additionally, any financial assistance may entail onerous paperwork, since public investment need a fully transparent audition. A bureaucratic approach, according to Taddeo (2016), may result in an inefficient development project.

The amount of olive oil and by products produced will be influenced by the volume and quality of olives that undergoes into the production process. As a result, the direct supply chain (olive oil selling) and the revalorization supply (by-product selling, in this case olive pomace) are both affected. The following examples clearly demonstrate this correlation (Figure 24):

If indeed the olive oil manufacturing results in a **surplus**, depending on their olive oil storage capacity or sales percentage the olive oil producer will need to make more product flow through the down-stream supply, so that olive pomace can be submitted to processes that will increase the product's stability and expand its utility. In terms of olive pomace, the quantity may get so high that olive oil producers will be, legally and operationally, unable to produce anything until olive pomace stock is dispatched from its facilities.

1)Transportation companies may not have enough fleet to handle the pick season (transportation requires special conditions: in both transportation modes, trucks should be having a controlled environment, allowing for effective control of the growth of pathogenic microorganisms or toxins, contributing for products degradation that could render them unfit for consumption), consequently not being available straight away, given the large number of companies producing olive oil at the same time; 2) It is possible that the treatment facilities may be unable to receive and store the quantities of goods received; 3) Treatment facilities may not be able to produce the quantity of product requested within the period of useful life of the bag- the time it takes to finish producing olive oil/olive pomace and begin revalorization might be so long that the product's conditions deteriorate; 4) And so on.

In case, there is a **shortage** in olive oil production, potential buyers of olive pomace will not be able to obtain the expected quantity of product and therefore will have to resort to alternative sourcing methods. As a result, the supply chain’s overall economic and environmental benefit and performance suffers, as sources of income are lower, and the alternative product supply may not be as environment friendly.

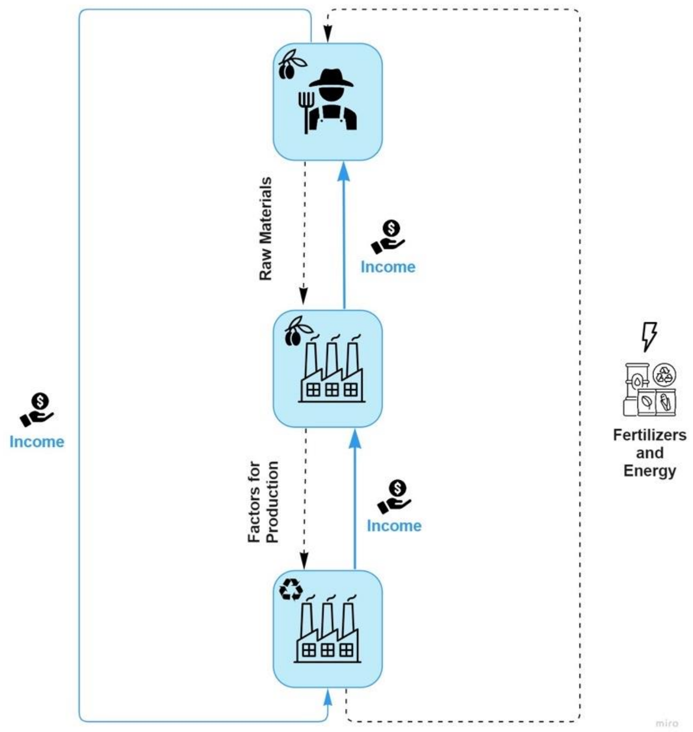


Figure 24- Flow of Material versus Flow of income

Several questions emerge in order to identify feasible approaches regarding the design and planning of a symbiotic supply chain, considering the three dimensions of sustainability, while using methods to measure the value of natural resources in economic, social, and environmental units (B. Taylor et al.,) Pressure to meet predetermined product flow levels. This might affect the chain's profitability or raise revenue unpredictability.

i) What is the network structure (closed loop, open loop, reverse).
ii) Available recovery alternatives (remanufacturing, Recycling, Energy recovery)
iii) Planning time horizon (technical, operational, strategic).
iv) What are the focus IS SC sustainability dimensions (considered in the objective function(s)- social, economic, environmental)? Whether they use simple or multiple objectives.
v) Enumerate SC variables (flow, inventory), parameters (area, capacity, distances, workers number) and constraints (max capacity, min stock). For example:

- **Capacity**: Will the revalorization plant have the necessary conditions, in terms of capacity, to receive/store and convert the desired amount of olive pomace or will more than one entity be required to fulfill this role?
- **Location**: If the transformation plant is located outside of the olive oil manufacturing facility/ area, will the distributor be able to transfer the volume of olive pomace? How will it impact in terms of operational costs?

To support decision-making concerning topics such as the number and location of the plants, their respective sizes, the quantity of stored product, and the regions they cover Models for Supply Chain Network Design and Planning can be used. A model is a representation of a certain reality, that tests alternatives or global behavior of a system. It uses representative data (e.g., characteristics of people, objects, or events) and must be able to model uncertainty in several parameters (e.g., demand, supply, products' price, and construction and transportation costs). Brandenburg et al. (2014) claim that for solving Supply Chain Symbiotic Models (SSCM) five main types of models are suitable: mathematical programming models, simulation models, heuristics, analytical models, and hybrid models. The choice of optimization method should be suitable for the type of uncertain parameters considered. According to Govindan et al. (2017), the most commonly used methodologies to model uncertainty in SSCM are stochastic programming, fuzzy programming, and robust optimization some common approaches in terms of mathematical modeling and solution approaches. Mathematical programming (MP) models formulate solutions in the form of mathematical objective functions; in general, these models are more objective than rating models because decision-makers can only focus on the objective function; however, this advantage can be seen as a disadvantage, as a MP model mainly considers quantitative criteria (Boer et al. 2001). Heuristics are easy and intuitive ways to deal with uncertain situations, but they tend to result in probability assessments that are biased in different ways depending on the heuristic used.

In fact, optimization models are often used in the literature to solve SC problems at a strategic (e.g., facilities location and capabilities), tactical (e.g., inventory management), and operational level (e.g. routing), when it comes to the development of the SC, which pays special attention to the network design problem. First, topics of interest are identified, and relevant data is collected. Then, mathematical models are developed, or existing models are adapted to the problem, by using analytical tools to help decision-makers make decisions.

According to Michael Porter, the strategy is to establish a unique and valuable position and cover various actions. The strategy is to swap and choose not to perform actions. If there is no choice, no strategy is required. A company's SC is directly related to a series of planning decisions, which are distributed hierarchically over several time horizons, including strategic level, tactical level, and operational level.

Microeconomic indicators are helpful in forecasting upcoming company performance regarding presumed demand and supply fluctuations, the allocation of resources, and the pricing at which they sell goods and services, considering taxes, regulations, and government legislation. The following are examples of microeconomic indicators: the price of raw materials in contrast to revalued by-products, customer satisfaction, and others. Macroeconomic indicators, on the other hand, will be vital to understanding a country's behavior and how its policies affect the supply chain as a whole. For example, inflation, gross domestic product (GDP) growth, and interest rates all have a significant effect on various sectors of the economy. Assuming that a supply chain is composed of firms from various industries, a change in the indicators will have a significant influence on a business driver or critical assumption. Suitable indicators to examine the achievement of set targets can be selected. There are several GRI indicators of sustainability, and Veloso V. (2019) nominated the most notorious ones through three distinct dimensions: economical, environmental and social. They have contributed for the scientific community with a noteworthy organized rank, by subdividing each dimension into three different levels of CE specificity: from level 1 (high level of CE specific) to level 3 (low to nonexistent level of CE specific), the following ones focus on the economic dimension (Figure 25):

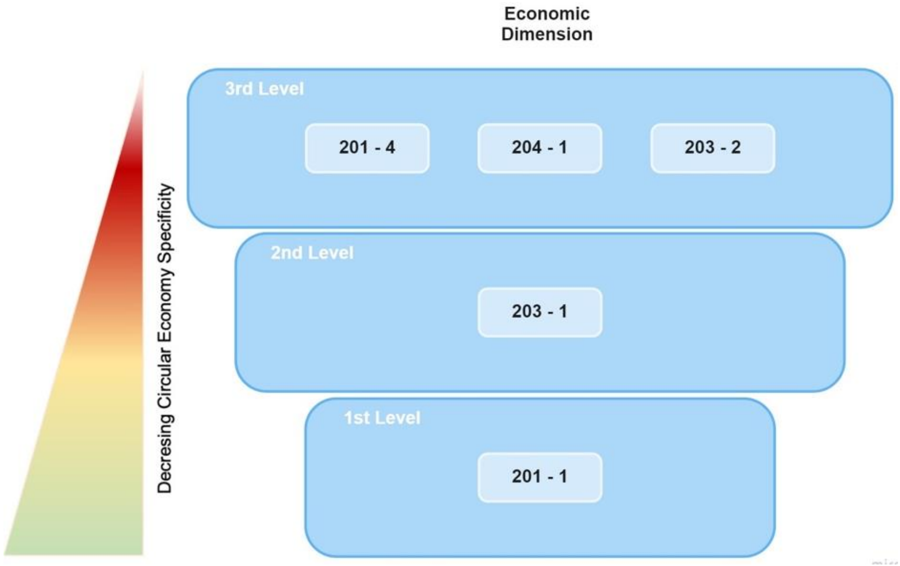


Figure 25- GRI Economic Standards

GRI Standard *204,* addresses the topic of suppliers' procurement, ***Disclosure 204-1 ("Proportion of spending on local suppliers"):*** states that the reporting organization should display the budget proportion that is being spent on local supplier's operations demonstrating if the firm helps the nearby economy, thereby the percentage of products and services purchased locally. Also, to reveal progress in the direction of a greater sustainable chain that stimulates a shift in customer purchasing habits and behavior, while defining the "critical operations".

Disclosure 203-2 ("Significant indirect economic impacts"): this metric allows to track how the introduction of new circular economy-related actions affects the innumerous supply chain stakeholders.

Disclosure 201-4 ("Financial assistance received from government"): enables one to examine if the enterprise(s) of a certain sector/site(s) got any type of state support in terms of financial backing, such as tax relief or subsidies/donations, during the period reviewed by the statement, and if so, what weight is represented in its final balance sheet.

Disclosure 203-1 will not be mentioned***.***

Disclosure 201-1 ("Direct economic value generated and distributed"): irrespective of the sector/ industry is one of the most commonly used economic indicators since it defines the economic profile of a company, in terms of profit sources as well as expense levels that the enterprise encounters with its activity, such as operational costs, payments, and investments, all of which adds up to total benefits. In addition, eventually reveals how the company's revenues are split across its stakeholders (dividends, loyalties, loans).

4.2.4.5 Level of Skills and Technology

Manufacturers are being driven to embrace new sustainable practices for a sustainable environment due to the huge importance of green activities and cleaner technology, in today's world. In a CE, cleaner technology refers to technologies that reduce water pollution, greenhouse gas emissions, green transportation, greener supply chains, and sustainable industrial processes (Moktadir et al., 2018). To be competitive, diverse supply chain players must exchange their information and ideas, which will aid manufacturers in launching new products. CE is motivated by the depletion of natural resources, energy, and public awareness of the relevance of environmental concerns. Proper training at internally and abroad is important for practicing and having comprehensive understanding about CE, which keeps them motivated. Furthermore, process flexibility might be attained by using general-purpose tools, equipment, and technology (Ulrich, 1995). For example, multi-skilled workers may lead to process flexibility (Miller 1992). Training for implementing IS also suffers from poor leadership and management practices. Adopting IS requires knowledge in multiple aspects such as technical and organizational expertise. Many people do not have awareness of IS concepts or sufficient understanding of IS terms due to a lack of means to educate potential players (Bacudio et al., 2016).

Also, partners' temporal advances of technology differ, and one of the biggest issues is the quick development pace of technologies (Tura et al., 2019). Furthermore, due to reduced knowledge and technological improvements. Demand for superior technology is smaller in poorer countries regions or for companies with low investment margins (Al-Tabbaa et al., 2019).

Industry 4.0 which includes advanced data analytics, forecasting techniques, IoT devices, and blockchain applications, among other others, are being used to meet the minimum requirements of modern supply chains, which necessarily require supply adaptability, methods and processes to optimize productivity, reduced or zero waste generation, resource planning, and more effective allocation of resources methods. The following figure is a small example adapted to olive pomace waste treatment reality, from Mastos et al. (2021) paper, which correlates the desire of minimizing supply chain environmental impact while implementing CE with the help of Industry 4.0.

The following example is assumed to have a track and trace technology alongside a blockchain process flow (Figure 26).

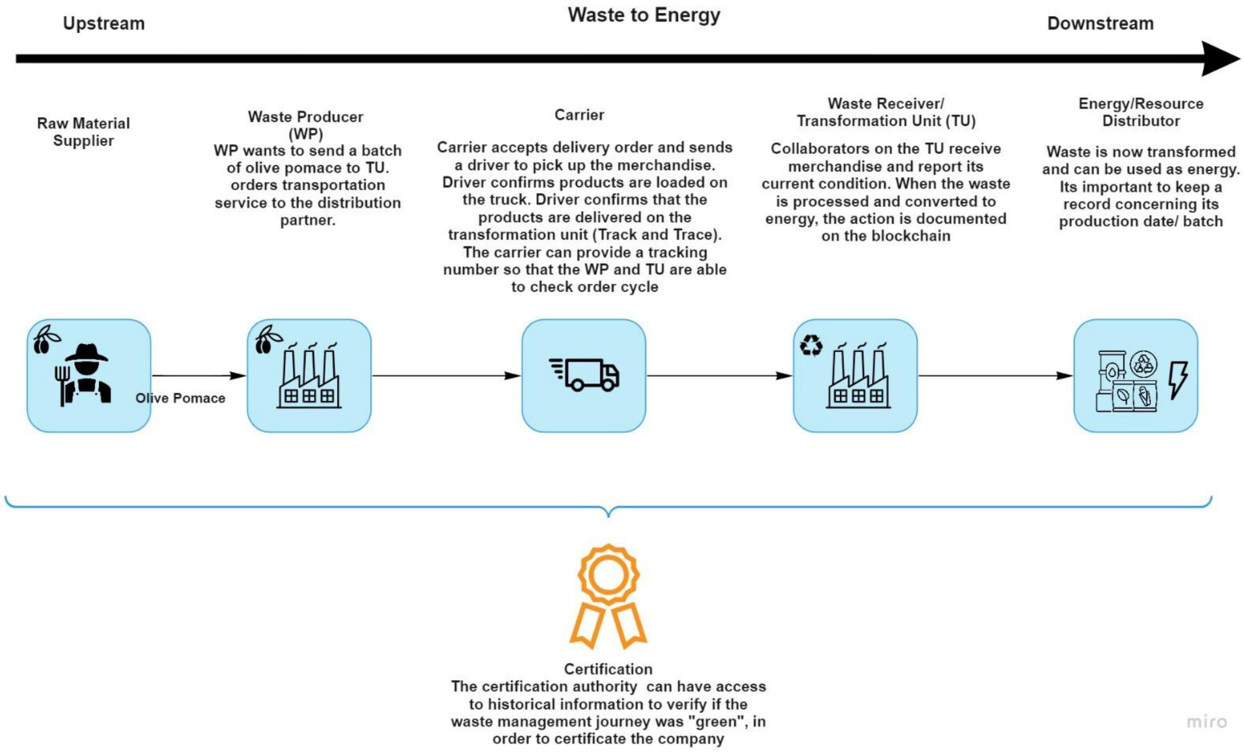


Figure 26- Example of a Blockchain Process Flow

4.2.4.6 Government regulations

Audits, inspections, and tax processes, as well as changes in tax legislation tend to change over the years and follow guarantee more wise and effective directions, rational use of natural resources, lessen the stress on ecosystems' regeneration ability, and promoting circular economy principles are some examples. Its interpretation or execution is a company's responsibility, if these are not properly addressed it may represent a negative impact on operating performance and financial situation (Catita et al., 2021).

According to the Portuguese Classification of Economic Activities, Revision 3 (CAE - Rev. 3), olive pomace recovery/ revalorization is included in Section E, which is part of the Recovery of Non-metal Waste (38322). This includes the recovery and processing (mechanical, chemical or biological) of non-metallic waste and scrap in products intended for further processing.

Bio-residue refers to the residues created during food processing, which means that olive pomace is categorized as bio-residue if it is not intended for oil production or animal feed, in which case, it is said in Article 91 (Sub-products) of Chapter IX (Declassification of waste) of the NRGGR, to be a by-product. By introducing the notions of biomass and biowaste, it is clear that residues formed after food processing are considered bioresidues, and that olive pomace is also termed bioresidue if it is not intended for oil production or animal feeding (in which case it will be by-product).

Defining the scope of waste management to better understand the regulation of procedures and the responsibilities of industries and based on the origin, quantity, nature, and typology of their waste. On December 10, 2020, the new general waste management regime was passed by Decree-Law No. 102-D/2020, which came into force on July 1, 2021.

The exclusion of some non-hazardous natural materials from the scope of the NRGGR is conditional on their origin and future use. This waste is exempt from the scope of the RGGR if used directly or after organic recovery in agriculture/livestock.

It is also worth noting that, in terms of the licensing of biowaste recovery operations, the general waste management regime in effect until July 2021 established that non-energy recovery of non-hazardous waste, when carried out by the producer of the waste resulting from his own activity, at the place of production or a similar place to the place of production belonging to the same entity, was exempted from licensing under point e) of paragraph 4 of Article 23. In turn, Article 66 states general rules may be laid down with regard on the authorization of waste treatment operations, as long as they define the waste treatment operation in question, and at least the types and quantities of waste, as well as the treatment method to which the waste is being forwarded to be recovered and/or disposed of in accordance with the principles outlined in this Law-Decree.

If, on the one hand, it appears that it could be applicable, the requirement for registration with the authority responsible for the municipal waste management system does not appear to be acceptable, as these entities have no responsibility for the waste in question and will be subject to targets that require strict accounting for the biowaste collected selectively and recovered. The *Autoridade Nacional de Resíduos* (ANR), a licensing entity, approves these general regulations after it is reported by *Autoridade Regional de Resíduos* (ARR) and posts them on the ANR website.

Accordingly, Article 91 (Sub-products) of Chapter IX (Declassification of waste) of the NRGGR, when a substance meets the following criteria, it is considered end-of-waste status:

a. there is a market or demand for that substance or object;

b. the substance or object is intended to be used for previously determined purposes;
c. the substance or object meets the technical requirements for the specific purpose and complies with the legislation and standards applicable to the products;
d. and the use of the substance or object no longer represents an adverse environmental or social impact.

Hence, the end-of-waste status has to be reviewed from the two following perspectives. When it is not intended to place the compound produced on the market, does not represent an issue. Nevertheless, if the producer intends to commercialize the valued compound, Decree-Law No 103/2015 and Decree-Law No 62/2006, lays down the rules to be followed when wishing to place on the market of fertilizer materials or biodiesel, respectively. While ensuring the implementation of Regulation (EC), states that the production of compost constitutes the end-of-waste status. When the recognition of the end of the waste status is reliant on a specific end use of the product and the operator does not redirect it to its end use, it must prove it when requested by ANR or other bodies with supervisory competence.

4.2.4.7 Complexity/ Responsibility

Complexities can appear in many forms, including ambiguity in data, diverse stakeholder engagement, increasing operational complexity, human subjectivity in judgments, linguistics, multiple sources of risk, sophisticated technology, and skill acquisition. Causal diagrams offer the ability to visualize the extent of interrelationships among barriers and provide important information to decision-makers. As the level of complexity rises, so does the level of responsibility assigned to each IS top player. Building an ISN, in the vast majority of circumstances, will entail duplication of tasks for leaders/individuals, making them reluctant in participating in a partnership, and ultimately joining forces and build a sustained IS SC. To better understand their duties and responsibilities, along with promoting and assuring risk prevention, top management should offer training and development opportunities to operators and team leaders. To achieve and maintain sustainable business models, riders must participate in workshops and offer time, personnel, and financial resources to find, appraise, implement, and run synergies (Kosmol et al., 2021).

The following presents a brief summary of the identified barriers (1), its potential causes (2), major impacts (3) and solutions (4) (Table 8).

Table 8- Brief Summary of the identified barriers, its potential causes, major impacts and solutions

Identification of barriers in symbiotic relationships	4.2.4.1 - Level of Trust and Commitment	1	Trust is directly correlated with the probability of maintaining a relationship and the level os transparency.
		2	A company's commitment is related with the dependency in its partners to perform its activities. Trust in other partners is expected to be low/non-existent when a company has no experience in IS relationships or no reputation in the field.
		3	The unavailability of data might result in increased uncertainty, worst rollout negotiations and less planning certainty.
		4	Find a facilitator in which all parties trust to share crucial information, e.g.: sharing information trough a secured online platform; Implement ISO 27001 and ISO 8000; Sign an agreement concerning privacy terms.
	4.2.4.2- Distintic Beliefs	1	Each company has its own autonomous planning and management procedures.
		2	The wider the geographical distance between each company's headquarters, the larger is the mental gap.
		3	Disparities in mentalities cause internal management and performance measurements. Which makes decision-making more challenging.
		4	Partners should define pain points, identify clear targets, priorizatize interests, define criteria and respective weights
	4.2.4.3- Risk and Uncertainty	1	What was once one's risk, will now become a diffused risk throughout all concerned stakeholders. Firms are vulnerable in environments characterized by diverse levels of uncertainty.
		2	Internal organization uncertainty, internal supply chain uncertainty, external supply chain uncertainty
		3	Diverse
		4	Outsourcing; Study operational variables and parameters (distances, capacities, input/output volumes); Insurance; Contract agreements; KPIs; ISO 31000; among others
	4.2.4.4- Economic and Operational Infeasibility	1	Assessing possible financial returns and the resources required to achieve the expected return is a very challenging process
		2	Power and position asymmetry influence resource and benefit allocation
		3	Operational inefficiency can cause products' shortages and surplus, lack of capacity, product flow constraints, which can represent negative impacts for economic dimension.
		4	Models for Supply Chain Network Design and Planning to optimize topics such as the number, location of the plants, routing and production plans. For economic feasibility, suitable indicators to examine the achievement of set targets are suggested.
	4.2.4.5- Level of Skills and Technology	1	Partners' temporal advances of technology differ. One of the biggest challenges is the quick development pace of technologies and new researches. Not every partner has the capability to follow the progress.
		2	Lack of investment and lack of interest
		3	if technologies become obsolete water pollution, greenhouse gas emissions, green transportation, and sustainable industrial processes
		4	Workshops and training, 4.0 Industry
	4.2.4.6- Government regulatio ns	1	Despite any changes to the management structure, a company will continue to respect every legal obligation. Exchanges can be particularly problematic if still these cannot legally be exchanged.
		2	The bureaucracy may not CE strategy-friendly due to the fact that it can be extensive and expensive
		3	If regulamentation is not correctly reviewed before transforming or commercialising, it may represent a negative impact on operating performance, financial situation and legal matters
		4	Waste Classification as to understand need of the legal process for authorizing revalorization alternatives and commercialization; Declassification of waste; Licensing
	4.2.4.7- Complexity and Responsibility	1	Duplication of tasks for leaders/individuals, makes them reluctant in participating in a partnership due to its complexity.
		2	Ambiguity in data, diverse stakeholder engagement, increasing operational complexity, human subjectivity in judgments, linguistics, multiple sources of risk, sophisticated technology, and skill acquisition.
		3	It may jeopardize the normal flow of core activities
		4	Participate in workshops and offer time, personnel, and financial resources to find, appraise, implement, and run synergies

4.2 Chapter Conclusions

The purpose of this chapter was to understand the limitations that hinder the development of complex symbiotic relationships in a given supply chain. As a result, taking into account the study's context, it was possible to compile a set of observations for the study, allowing it to characterize the management of intra- and inter-corporate relationships. For each of the aforementioned barriers, it was then attempted to devise a set of solutions or performance indicators in order to determine if the existence of certain relationships are reasonable. The last chapter of the dissertation presents the final conclusions, the study's limitations, as well as future research opportunities.

5 Conclusions and Future Work

This chapter summarizes and draws conclusions from the entire work presented. It highlights the significance of further Industrial Symbiosis investigation and judgments concerning the researched barriers and suggested recommendations. Also, comments and feedback are provided for additional steps that might be taken to improve the solution.

5.1 Study Conclusions

The present dissertation intends to introduce the concept and promote the Circular Economy study in the olive oil's industry, specifically in the Portuguese market. It focuses on a commonly faced challenge among companies, which is their uncertainty about the establishment of successful industrial symbiosis relationships within a supply chain. A successful IS relationship must, at least, provoke enhanced environmental results. Also, when a relationship is created, it must be ensured that the quality of the delivered service or product will not be compromised and subsequently, not causing negative consequences to the company in the long term. From this perspective, the current study differentiates from previous literature by widening to a multi-sided collaboration dimension (equal to or more than 4 participants) within the same SC, rather than focusing on simple IS relationships from different SC.

Industrial Symbiosis is only attainable at a group level, and it can be one of the key strategies for managing resources and waste from stakeholders such as businesses, communities, policymakers, institutions, and organizations. Therefore, synergies between different stakeholders can help maximize waste utility, through energy production, and organic transformation, among others.

Apparently, olive oil's consumption, production, and export have been increasing over the years and it is believed that it will continue to do so on a global scale. There is a growing concern to transform this sector into a more sustainable one, so that the industry can sustain itself for upcoming generations, in terms of resources, revenues, and employability rate for the European countries. Today's legal requirements force manufacturers to hold responsibility for the waste they produce, which may be difficult for manufacturers to take control of disposal operations while focusing on their core business. Having this said, the existence of collection centers and retrieving entities that work together with traditional supply chain entities is crucial, as to avoid the uncontrollable rise of waste flow that is disposed of in landfills.

In order to provide sufficient knowledge on the topic, an extended literature review has been developed. It aims to define the main concepts, according to different authors, while framing the existence of sustainability in supply chains. The assessment of their effectiveness has been based more on empirical observations rather than on theorical judgments. After having identified system’s primary entities (e.g., manufacturer, distributors), the level of analysis (e.g. supply chain), the process of analysis (e.g. deliver, make, plan, return, source), functional application (e.g. logistics, network design), the next step was to gather information concerning inherent and inevitable barriers, that prevent individuals from joining a multi-sided collaboration.

The empirical observations made above demonstrated that the influence of particular barriers and motivating factors varies enormously depending on the context. Thereby, the assessment of compatibility, between processes or companies, is mandatory for a viable IS, because while assessing possible barriers, the companies' compatibility may be questioned. The parts engaged in establishing a synergetic relationship should not directly replicate the strategy from one context to another. A business strategy that is successful in a specific context may fail in a more complex one. Every system’s environment has to be properly studied, externally and internally, before designing a SCCS strategy.

Firms are vulnerable in environments characterized by diverse levels of **uncertainty** especially working with multiple partnerships from different sectors. Also, the level of **trust** can influence a company’s transparency. This can be a supported by adapting level of **skills** and **technology**, that can be leveraged with the correct investments and top open-minded management. The barriers regarding the **distinct beliefs** and the intrinsic **operational** and **economic** objectives of a company can highly influence decision making process in terms of judgements and timings. The amount of effort necessary to achieve major changes in operations, represents complexity of newly formed relationships. Furthermore, the duty of each organization is proportional to the quantity and complexity of operations, which is expected to greatly increase. Furthermore, **government** regulation in areas where waste management policies have not evolved towards more ecological approaches might still be seen as a strong barrier. In order to protect, restore, and enhance environmental quality the government can implement strategies such as government subsidies, demystification of waste classification, financial assistance, tax relief, and others.

Through the analysis of several articles concerning the industrial symbiosis framework, a few still bridge the gap between literature on known barriers of a 2:3 (waste: resource relation) IS relationships, typically close to each other geographically, to real-world applications. This study takes place at a more complex level: on a multi-sided collaboration within a certain supply chain. A special emphasis should be given to the lack of articles exploring all three pillars of sustainability, while describing possible system barriers and potential solutions.

The identification and arrangement of certain barriers with potential solutions and performance indicators, that would reduce barriers' impacts, was extremely difficult. A core aspect of this study is the need to reinvent sustainability measures that can be adapted to certain organizations at a business-competitive level. The lack of research connecting some of the supply chain concepts with the IS strategy was noticeable. Furthermore, the main goal of this study was to highlight the gap in supply chain research with symbiotic relationships and propose future research directions.

5.2 Recommendations for future Work

Evidently, every work has its flaws, ups and downs, and this one is no exception. In the present case, the author may have noticed that some of the recommendations are only applicable under certain sectors or a particular supply chain, although some of the remarks describe more general recommendations. If the offered solutions are chosen for implementation, further comprehensive information will be needed. It would be interesting to develop a simulation of a multi-sided collaboration, with all factors included, in order to assess the real impacts of implementing this solution concerning all three dimensions of sustainability. To do so, it will be needed to understand the benefits and disadvantages of each relationship, analyze constraints, analyze each player's perception of value, assess opportunities and risks to the business, and assess the companies’ strategic positions. Also, it would be interesting to quantify the potential impacts of establishing different relationships between one supply chain level and another, allowing the collection of useful information to examine the decomposition of potential trade-offs. In these situations, a method that analyzes the influence of one factor on another, while establishing premises, and making predictions without causing changes to the other variables, is recommended.

All things considered, and despite the unforeseen, it is hoped that the scientific community finds that this thesis helped better understanding simultaneously the notions of circular economy, symbiotic industry, and supply chain, even though further investigation on the subjects seems to be required.

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