

## Circular Economy: Challenges and opportunities in supply chain management

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June 2022

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**Abstract:** Over the years, it is possible to notice an increase in environmental pollution associated with the industrial sector. As such, the research community felt the need to take initiatives to address the problems associated with the environment, developing tools that would offer the opportunity to grow economically, however, disassociating this growth from the increase in environmental damage.

In 2010, with the creation of the Ellen MacArthur Foundation, the concept of Circular Economy was developed which, applied to the supply chain, would result in a shift from a linear and traditional produce-use-waste model to a circular model. The Circular Economy allows for the reuse of by-products and waste generated along supply chains and consequently decreases the damage done to the environment.

This paper aims to identify and characterize the implications of Circular Economy in supply chain management, understanding what the challenges and opportunities of this adherence are. Therefore, it will be explored concepts associated with the Circular Economy and how they relate to supply chains, identifying the stakeholders involved, circular business model strategies, circular indicators, Industry 4.0, and the application of Industrial Symbiosis. As this is a generally poorly explored theme, three frameworks will be developed, a conceptual map, a stakeholder matrix, and finally, a framework that covers the opportunities and difficulties of applying Circular Economy. Finally, cases of application of Circular Economy in the forestry and agricultural sector in Portugal, and an international case will be addressed.

**Keywords:** Circular Economy, Supply Chain, Circular Supply Chain, Supply Chain Management, Industrial Symbiosis

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### 1. Introduction

#### 1.1. Motivation and contextualization

The Circular Economy is currently growing worldwide, as opposed to the linear production and consumption model, since the last has proven to be unsustainable (Hamam et al., 2021). However, despite this remarkable growth, there is still much to be explored when it comes to the applications of the Circular Economy and its concepts, especially in the logistics area.

If the level of consumption is maintained and there is no change in the way products are obtained, produced, delivered, used, recovered, and regenerated, natural resources will run out in the near future (Farooque et al., 2019). Hence, it is crucial that companies begin to adhere to circular practices and promote sustainable development. The innovation of the Circular Economy concept has allowed the development of technical processes that facilitate the adoption of circularity in supply chains (Hussain & Malik, 2020). Thus, the concept of Circular Supply Chain refers to chains that create value through products/services, by-products and useful waste streams over longer life cycles that promote environmental, economic, and social sustainability (Batista et al., 2018).

#### 1.2. Problem description

It is increasingly required to take measures that enable sustainable development both socially, economically and environmentally, due to the increase in global consumption

and the consequent degradation of the environment. The 21st century is facing several challenges, namely biodiversity loss, climate change, resource and water scarcity, population growth, and economic difficulties (Hamam et al., 2021). It is estimated that by 2050, natural resources will be limited as the population is expected to reach 9 billion (Hamam et al., 2021). This coupled with the increase in the population's consumption parameters is one of the factors that demonstrates the need to turn to more sustainable initiatives (Hamam et al., 2021).

Since the linear supply chains are one of the causes for the degradation of the environment and the resources, it becomes necessary to take sustainable measures to address this problem. In this way, the concept of Circular Economy was developed, which allows the shift from a linear model to a circular one, where it excels in the prevention of the environment and the reuse of by-products and waste generated.

Circular Economy is a recent concept, which in turn results in a weak exploration of it and of the other supply chain and Circular Economy related concepts. Thus, one of the problems to be solved in this work is the clarification and description of the concepts of this theme. Furthermore, due to the application of Circular Economy to supply chains, it is crucial to understand how this concept influences the management of these chains, covering both the analysis of circular stakeholders and the circular business model, analyzing what changes need to be made in order for a successful transition to occur. We also analyze the practice of Industrial Symbiosis that, despite being little developed

in Portugal, it is better understood through the experience gained by companies already operating in this environment. In this way, to assist the lack of information available, we discuss the application of the concept in supply chains, the industrial context in Portugal, the challenges and future of these practices, and finally, we report two cases of Industrial Symbiosis in Portugal, from two different sectors, and a case that stands out internationally.

Furthermore, in order to evaluate the performance of the application of Circular Economy in supply chains, it is necessary to use circular indicators. Thus, a problem associated with this area is the lack of definition of tools and criteria measuring the circularity of products, companies, or regions (Rincón-Moreno et al., 2021). Also, in terms of technological development, it becomes necessary to understand how Industry 4.0 can be used in the application of circular concepts to help achieve sustainable development.

In general, it is crucial to understand how to adapt supply chains and their management to become more circular.

### 1.3. Objective

The main objective of this work is to study the implementation of Circular Economy in supply chains, through the development of frameworks to evaluate and support decision making regarding circularity, addressing the opportunities and difficulties in supply chain management.

The adherence to the Circular Economy, allows sustainable development both at environmental, economic, and social levels, allowing the decoupling of economic growth from environmental degradation and resource destruction (Masi et al., 2017). Hence, the objective of this work is the presentation and development of tools that can assist in the implementation of the Circular Economy in supply chains management, understanding the challenges and opportunities in a Circular Supply Chain. As these are concepts that have not yet been sufficiently explored, especially in the logistics area, it is necessary to develop tools and frameworks that can help companies better understand the concept and take a first step towards circular practices.

## 2. Characterization of Circular Economy in supply chains

### 2.1. Concept analysis table

Given the complexity, diversity, and still scarce exploration of the concepts of Circular Economy in their application in supply chains, a table was built, which analyzes the number of works that address these concepts and other related ones over the years, resulting in an elucidative analysis of the growing importance of these concepts in supply chains. It may be noted that before concepts related to the Circular Economy and supply chains were part of the top areas of Operations Research and Management Science in supply chain research, they started to be explored in more sectorial areas, as is the case for example in the Journal of Cleaner Production.

The concept of Circular Economy was mentioned first when the Ellen MacArthur Foundation was created in 2010. Despite the growing trend that it presents, this concept is still very little mentioned, especially in its application in supply chains. Furthermore, the concepts of Reverse Logistics and Closed Loop Supply Chain, only began to be mentioned in the logistics areas as of 2005, the year in which the Kyoto Protocol and the Emissions Trading System came into force. Besides this, the Circular Economy, Reverse Logistics, Closed-Loop Supply Chain, Green Supply Chain and Sustainable Supply Chain concepts have grown over the years. Nonetheless, in a more general perspective, we conclude that this is a theme that has not yet been properly studied and deepened, but that in turn, presents a growing trend over the years.

### 2.2 Analysis and clarification of Circular Economy concepts

The Circular Economy corresponds to an economic system that excels in reducing not only the use of new resources, but also waste, emissions, and energy leakage (Geissdoerfer et al., 2020). This can be achieved by using cycles, extending them; intensifying the reuse of materials and energy; dematerialization of materials and energy circuits, resulting from digitalization, maintenance, sharing solutions; creation of products with a long lifespan; maintenance; repair; reuse; remanufacturing; refurbishment and recycling (Geissdoerfer et al., 2020). In addition to this, in the Circular Economy, industrial production uses restorative (giving new life, promoting recovery to the initial state) and regenerative (recovering to a new, improved state) methods, which allows products to remain with high long-term utility and value (Batista et al., 2018).

Sustainable Supply Chain Management refers to the management of material, information, capital flows and the collaboration between companies, focusing on the economic, environmental, and social dimensions of the Supply Chain (Hussain & Malik, 2020).

Whereas, a Closed Loop Supply Chain, refers to when the products go from the consumers to the original producer, where afterwards a part of the product or the total product is reused (Batista et al., 2018). In this way, this is defined as being a logistical process that has as its main objective not only to reduce the creation of waste, but also to reduce the use of raw materials (Sehnm et al., 2019).

Besides this, Reverse Logistics covers the entire process of planning, implementing, and controlling material return flows (Geisendorf & Pietrulla, 2018). Thereby, the concept of Reverse Supply Chain can be present in both an Open Loop Supply Chain and Closed Loop Supply Chain, as, in the former, this refers to when materials are recovered by other entities, other than the original producers (Batista et al., 2018).

Another concept of high importance in this theme is Industrial Symbiosis, which refers to ecological cooperation between industries (Sehnm et al., 2019). It is a component of Industrial Ecology and allows the surrounding entities to gain competitive advantage due to the exchange of materials, energy, water, and by-products (Turken & Geda,

2020). It allows knowledge to be created and shared, and there are mutually beneficial transactions (Turken & Geda, 2020). To finalize, the concept of Symbiotic Supply Chain is the combination of two concepts, Supply Chain Management, and Industrial Symbiosis (Turken & Geda, 2020). It is related to both external and internal organizations, namely suppliers, manufacturers, warehouses, buyers, and the processes that generate the products and their distribution (Turken & Geda, 2020). The symbiosis network, allows the expansion of a traditional supply chain, that is, it also encompasses the suppliers, buyers and the resources and information shared by the other companies (Turken & Geda, 2020).

### 2.3. Circular Economy in supply chains: Concepts in developing a Circular Supply Chain

There is little information on Circular Supply Chain Management, and its concept refers to the application of circularity not only in the supply chain management, but also in their surroundings (Farooque et al., 2019). By applying the Circular Economy, a zero-waste perspective is promoted through the development of the business model and the supply chain functions, with certain precautions regarding product/service development, waste treatment, and end-of-life products, and by allowing the involvement of stakeholders in the whole process (Farooque et al., 2019).

A Circular Supply Chain can function with forward and reverse flows that create value through products/services, by-products and useful waste streams over longer life cycles that promote environmental, economic, and social sustainability (Batista et al., 2018). The product design enables the repair and remanufacturing, which ensures, the reduction of material flow, resulting in cleaner production and increased resource efficiency (Hussain & Malik, 2020). As so, Circular Supply Chain is related to the closing, narrowing, slowing, intensification and dematerialization of material cycles (Hussain & Malik, 2020).

It is also possible to note some differences between Closed-Loop Supply Chains and Circular Supply Chains, i.e., in Circular Supply Chains there is an expansion of the Closed-Loop Supply Chain, both in scope and focus, allowing the existence of flows to other supply chains (Batista et al., 2018). The concept of Circular Supply Chain expands the closed-loop perspective thanks to the creation of value chains from the return of products at their end of life and from by-products and waste streams that have been recovered thanks to reverse and direct cascade chains (Farooque et al., 2019). These chains are linked to the 3 Bottom Line perspective which, in turn, refers to the division of organizational sustainability into 3 components, the environment, society and economy (Farooque et al., 2019).

## 3. Implications of Circular Economy in Supply Chain Management

### 3.1. Circular Supply Chain Stakeholders

The life cycle of a product is essential to assess, in terms of sustainability, the positive and negative impacts, in order to

conclude the value created for the main stakeholders, namely, producers, consumers and society in general (Hapuwatte & Jawahir, 2021). In addition to this, supply chain management and operational practices are increasingly being impacted by sustainability, and this is due, not only to increasing economic performance, but also to the environmental and social responsibility of key stakeholders (Batista et al., 2018).

In order to identify the opportunities for value creation to each stakeholder, the interactions between stakeholders should be identified and analyzed (Hapuwatte & Jawahir, 2021). Thus, it is crucial that collaboration occurs between different stakeholders in order to result in more sustainable behaviors (Hamam et al., 2021). Besides this, the presence of both primary and secondary stakeholders is of high importance in the implementation of circular innovation (Eisenreich et al., 2021b). It can be pointed out that in the case of the decision-making and evaluation processes of the measures aimed at implementing circular innovation, these are influenced by stakeholders internal to the company (Eisenreich et al., 2021a).

### 3.2. Circular Business Model

A business model indicates how resources, competencies, and partnerships, intended to result in the creation and capture of value, are identified and used (IAPMEI, 2005). In this way, not only are value propositions created, but also customer segments are identified, showing how to relate to them (IAPMEI, 2005). As such, the business model describes how a supply chain functions in terms of value creation and capture, and in turn it is necessary to understand which stakeholders to take into consideration and how their interests will influence the supply chain and be influenced by it. And then, subsequently, develop a circular business model.

The sustainable business model has a subcategory called circular business model (CBM), which allows closing, intensifying, narrowing, and dematerializing the materials cycle (Galvão et al., 2020).

Therefore, in order for companies to meet their social as well as environmental ambitions, it is necessary that their business model is innovated through circular strategies applied in the material and energy cycles, such as a cycling, extending, intensifying, and dematerialising strategy (Geissdoerfer et al., 2020). This results in a reduction not only in the amount of resources used, but also the waste and emissions created (Geissdoerfer et al., 2020).

The two approaches that most affect the business model are the strategic partnerships to achieve circularity and involve stakeholders in the value chain, and secondly, the use of technology to adhere to circular practices. In addition to this, it can also be observed that, the business model blocks that are the most influenced by Circular Economy are the customer segment, customer relationships, and key partners (Salvador et al., 2021).

### 3.3. Industrial Symbiosis in supply chains

Industrial Symbiosis is a strategy that supports the transition to the Circular Economy (Fraccascia &

Giannoccaro, 2020). However, although the concept of Industrial Symbiosis has a growing trend over the years (Turken & Geda, 2020), it is still poorly explored.

The Industrial Symbiosis leads to the collaboration of different entities in the exchange of waste and resources, consequently generating a competitive advantage (Turken & Geda, 2020). It has a considerable impact on the design of supply chains and the relationships between participants (Turken & Geda, 2020), since it encourages the exchange of materials, water and energy flows between industrial partners, allowing an effective symbiotic industrial relationship (Hussain & Malik, 2020).

Decisions at the strategic level refer to impacts on the organization in the long term, such as the design of the supply chain network and the organization and its regulations and objectives (Turken & Geda, 2020). As for tactical level decisions, these focus on issues directed at material flow, for example, not only production and inventory levels, but also logistics, lot sizes, and others (Turken & Geda, 2020). Regarding the operational level, it is critical to have management of variability in quality and quantity of by-products and waste to be successful at this level (Turken & Geda, 2020).

There are three types of Industrial Symbiosis, namely, self-organized, facilitated, and top-down (Turken and Geda 2020). Firstly, regarding self-organized, it is possible to observe a greater success when Industrial Symbiosis is applied through coordination between companies than through governmental policies (Turken & Geda, 2020). Regarding the facilitated type, it refers us to a facilitating entity that can come from the private or public sector, which assists in the symbiotic relationship (Turken & Geda, 2020). As for the top-down type, it is an underdeveloped area and still only applied in China, which reinforces the importance of legislation to encourage the improvement of 3 bottom-line companies (Turken & Geda, 2020).

When it comes to the geographical location of industries, Industrial Symbiosis usually refers us to symbiotic relationships between industries that are usually geographically close and are economically independent, with long-distance networks proving to be not very feasible (Gábor Herczeg et al., 2018).

### 3.4. Circular Economy indicators in supply chains

There are several factors that influence companies' adherence to the Circular Economy, one of them being the lack of indicators and targets (Saidani et al., 2019). However, due to the demand for the transition to the Circular Economy, an increasing trend in the development of circular indicators can be observed (Saidani et al., 2019). In addition to this, another issue involved in this process is the lack of knowledge on how to measure performance and progress at different levels (Saidani et al., 2019)(Rincón-Moreno et al., 2021). Since the measurement of circularity of products, firms, and regions does not have the same set of standard indicators between them (Rincón-Moreno et al., 2021).

Also, the author Moraga et al., (2019) argued that most indicators are related to material preservation strategies, this is because, Circular Economy focuses on recycling, this

being the most frequent strategy in Circular Economy. As such, it is possible to conclude this is still an area that needs further investigation.

### 3.5. Industry 4.0 in Circular Economy

Industry 4.0 is related to an intelligent and autonomous industry, where the focus is on making processes more economical, intelligent, and efficient, resulting in changes in the design of products and materials and their operations and transportation (Dantas et al., 2021).

Therefore, with the support of Industry 4.0, it allows managers to locate, monitor and make sustainable decisions concerning products (Dantas et al., 2021), that are recovered after their consumption, by collecting and sharing data on machines, production, operations and component flows (Khan et al., 2021).

Also, Industry 4.0 has changed the structure of supply chains through the application of more developed technologies, changing how suppliers, producers and consumers participate in sustainable development solutions, improving their performance in terms of social, economic, and environmental aspects (Khan et al., 2021). Thus, the logistics sector underwent a major change thanks to I4.0, since it resulted in the change of business models and the implementation of new technologies in supply chains (Kumar et al., 2021), which allowed a better prediction of customer demand and an optimized supply chain management (Ciliberto et al., 2021). However, it should be noted that the development of Industry 4.0 has negative impacts on the environment due to the use of large information centers, technological equipment, and sensor devices, which require a significant amount of energy and resources (Sharma et al., 2021).

It can be noted that additive manufacturing, cyber-physical systems, simulation, and the internet-of-things all have a considerable impact on product lifecycle management (Rosa et al., 2020). Furthermore, big data and analytics is more related to digital transformation (Rosa et al., 2020). The recycling is strongly influenced by additive manufacturing (Rosa et al., 2020). Besides this, simulation affects considerably the circular business model and the supply chain management (Rosa et al., 2020).

## 4. Circular Economy in Portugal

### 4.1. Industrial Symbiosis in Portugal

The most prevalent type of Industrial Symbiosis in Portugal is self-organized, where it is the companies that take the initiative to implement new practices and create symbiotic networks, this is because, each network is composed of few participants and in cases of networks with two or three companies, they are in the same area or in close areas (Neves et al., 2019). The largest and most organized network in Portugal is the Eco Industrial Park of Relvão, located in Chamusca (Neves et al., 2019).

There is no plan in Portugal aimed at the implementation of Industrial Symbiosis (Neves et al., 2019), in this way, to encourage this practice is through the provision of a large area for industries, accompanied with the promotion of meetings for the establishment of relationships and with

the development of facilities for waste management, allowing the development of Industrial Symbiosis networks (Neves et al., 2019).

In Portugal, there is a higher number of cases in Alentejo, more specifically in Lezíria and, regarding the activities in which Industrial Symbiosis is inserted, there is a higher concentration in production activities (56%), with a higher prevalence in the paper, pulp and cement industry (Neves et al., 2019). The activities that are related to agriculture and cattle breeding, are the second most present in the application of Industrial Symbiosis and these are mostly present in Alentejo and Lezíria do Tejo (Neves et al., 2019). Nonetheless, one of the most important aspects mentioned by the author Neves et al., (2019) is the existence of a larger number of cases of Industrial Symbiosis in Portugal, than those that are actually reported (Neves et al., 2019).

## 5. Circular Supply Chains: implementation in and outside of Portugal

### 5.1. Case of Circular Supply Chain in the forestry sector in Portugal

In the forestry sector, it is estimated that approximately one third of Portugal's territory is forest (Sirous et al., 2020), and this makes it of economic interest to invest in the exploitation of biomass from this sector (Gonçalves et al., 2021). As such, being the world leader in the cork sector, the case of Corticeira Amorim will be discussed.

Cork is considered a paradigm of the Circular Economy, since in this sector there is a great focus on recycling, collection, and transformation of cork (PBS, 2017). Hence, Corticeira Amorim has developed an extraction process with low environmental impact and synergies with materials and by-products generation (BSCD Portugal, 2020). In addition, it is a 100% natural, renewable, resistant, versatile and easy to reuse product generation (BSCD Portugal, 2020).

By adopting the Circular Economy, Corticeira Amorim allows for the reduction of waste created, extends the useful life of materials, and promotes the regeneration of natural systems generation (BSCD Portugal, 2020). Hence, the company has 63% of its energy from biomass, a waste recovery rate of over 90% and promotes environmental education programs (*Corticeira Amorim*, 2022). Nonetheless, the company's main challenges are to improve the efficiency of resource use, the sustainable management of the use of chemicals and the reduction of waste generation (BSCD Portugal, 2020).

### 5.2. Case of Circular Supply Chain in the agricultural sector in Portugal

Although the population continues to grow, increasing food production is not seen as an option since not only does it involve high costs and there is a need for already scarce natural resources, but it is also estimated that a third of the food that exists worldwide is wasted (Hamam et al., 2021).

The main factors that contribute to food loss are inadequate infrastructure, climatic and environmental factors, and safety and quality standards (Hamam et al., 2021). As such, it is necessary to find a method to add value

to the supply chain by minimizing food losses and food waste in both production and consumption (Hamam et al., 2021).

By combining Industry 4.0 and the Circular Economy, it is possible to have greater visibility, traceability, and trust between the different stakeholders (Kumar et al., 2021). On the downside, there is the disadvantage that this model is associated with high costs for the company due to lack of technology, incorrect government policies, and lack of awareness among farmers (Kumar et al., 2021)

Furthermore, in the application of circularity in agricultural production, both plant and animal, it is argued that plant biomass is the basis of the food system of individuals and that it should be used to produce food (Velasco-Muñoz et al., 2021). As far as by-products are concerned, these would be reused or recycled in the food system. In animal biomass, this would be used to create manure, among others (Velasco-Muñoz et al., 2021).

Nonetheless, the valorization of waste and by-products in the production of Alentejo wine is of high importance, and the main waste and by-products are vine prunings, stalks and marcs (Bruno Magalhães et al., 2017). In addition to these, there are the dregs and sludge from Wastewater Treatment Plants and potassium tartrate (Bruno Magalhães et al., 2017).

One can observe in Alentejo, the sharing of facilities and resources between the olive oil and wine industries, resulting in the reduction of costs and the promotion of competitiveness of both industries (Bruno Magalhães et al., 2017). Hence, these share not only social areas and waste management, but also offices, warehouses, laboratories, and equipment (Bruno Magalhães et al., 2017).

### 5.3. International case of Circular Supply Chain

Cisco is a company that stands out on an environmental level, in this way, this company follows five principles of circular design in their supply chain, such as, the use of recycled materials in products to reduce the use of non-renewable materials (Cisco, 2022). Next is the standardization and modularization of components to simplify the supply chain and enable the circular practices of reuse, repair, remanufacturing, and recycling (Cisco, 2022). With regard to packaging and accessories, recycled and renewable materials should be used, reducing the amount of foam and plastic, and increasing their efficiency (Cisco, 2022). Also, smart energy consumption allows for better energy efficiency of products, and finally, in disassembly, repair and reuse, products should be used with components that facilitate the circular practices of reuse, repair, remanufacturing and recycling, resulting in longer product life (Cisco, 2022).

Furthermore, Cisco developed a program, Product Takeback and Reuse, where consumers would return their hardware at the end of its life, free of charge (Cisco, 2022). Resulting in 99.6% of the products that are returned to the company being reused and recycled (Cisco, 2022).

## 6. Proposed framework and recommendations

### 6.1. Conceptual Map

The concept map was developed with the objective of solving the problem that this is a theme composed of a wide variety of recent concepts that are not well defined and are not properly distinguished from one another. In this way, the concept map is composed of the main concepts and shows how they are related, thereby facilitating the understanding of the theme and the importance of each component explored. This map can be seen in figure 1.

### 6.2. Stakeholder matrix

A stakeholder matrix is a very important tool, as it provides an overview of which individuals are most important when joining the Circular Economy in a supply chain, and analyses not only how they influence the Circular Supply Chain, but also how stakeholders are influenced by it.

In order to develop a stakeholder matrix, it is necessary to identify the stakeholders, understand their power and interest, and then position them in the matrix. Thus, in table 1, you can see the list of stakeholders and the authors who mentioned them.

Table 1 - Stakeholders Identification  
Source: Autor

	Bellantuono, Pontrandolfo, e Scozzi (2016)	Govindan e Hasanagic (2018)	Eisenreich, Füller, e Stuchtey (2021b)
Consumers	X	X	X
Suppliers	X	X	X
Employers	X	X	
Employees	X	X	X
Government	X	X	
Society		X	
NGO			X
Shareholders	X		
Consulting company			X
Competitors	X		
Media	X		
Business Partners	X		
Universities			X

As such, after surveying the stakeholders, they are positioned in the matrix that evaluates their power and interest in the Circular Supply Chain. It's possible to observe the stakeholder's matrix developed in figure 2.

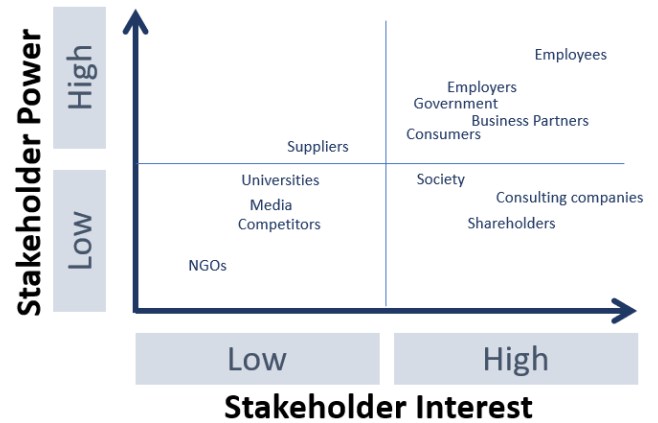


Figure 2 – Stakeholder Matrix

Source: Autor

### 6.3. Enablers and challenges of the Circular Supply Chain

Lastly, a tool has been built that focuses on giving an overview of the enabling mechanisms and the challenges that may arise when developing a Circular Supply Chain, as seen in figure 3. In this way, we are presented with the tools to successfully join the Circular Economy, as is the case of the circular business model, the development of a Symbiotic Supply Chain, and by assisting adherence with Industrial Symbiosis and Industry 4.0. To understand what challenges may be present, and to facilitate the mitigation and prevention of problems, part of the tool developed is composed of the risks, uncertainties, and with an approach to the challenges from an economic perspective.

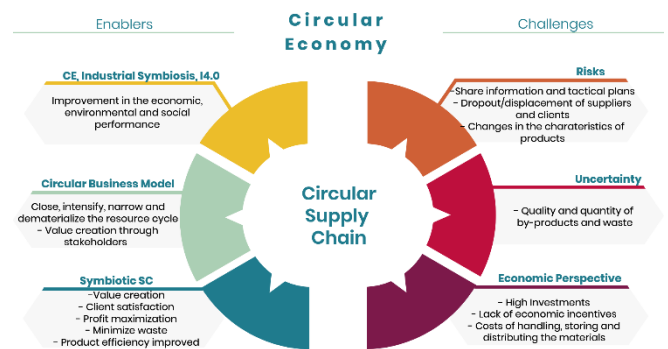


Figure 3 - Enablers and challenges of applying Circular Economy

Source: Autor

This diagram was developed to relate the main points of the Circular Supply Chain management, relating the areas mentioned throughout the work, since the literature on the application of circular practices in a supply chain was scarce, focusing more on a conceptual way, and not in how the Circular Economy should be applied and what measures should be taken so that the adhesion occurs with success.

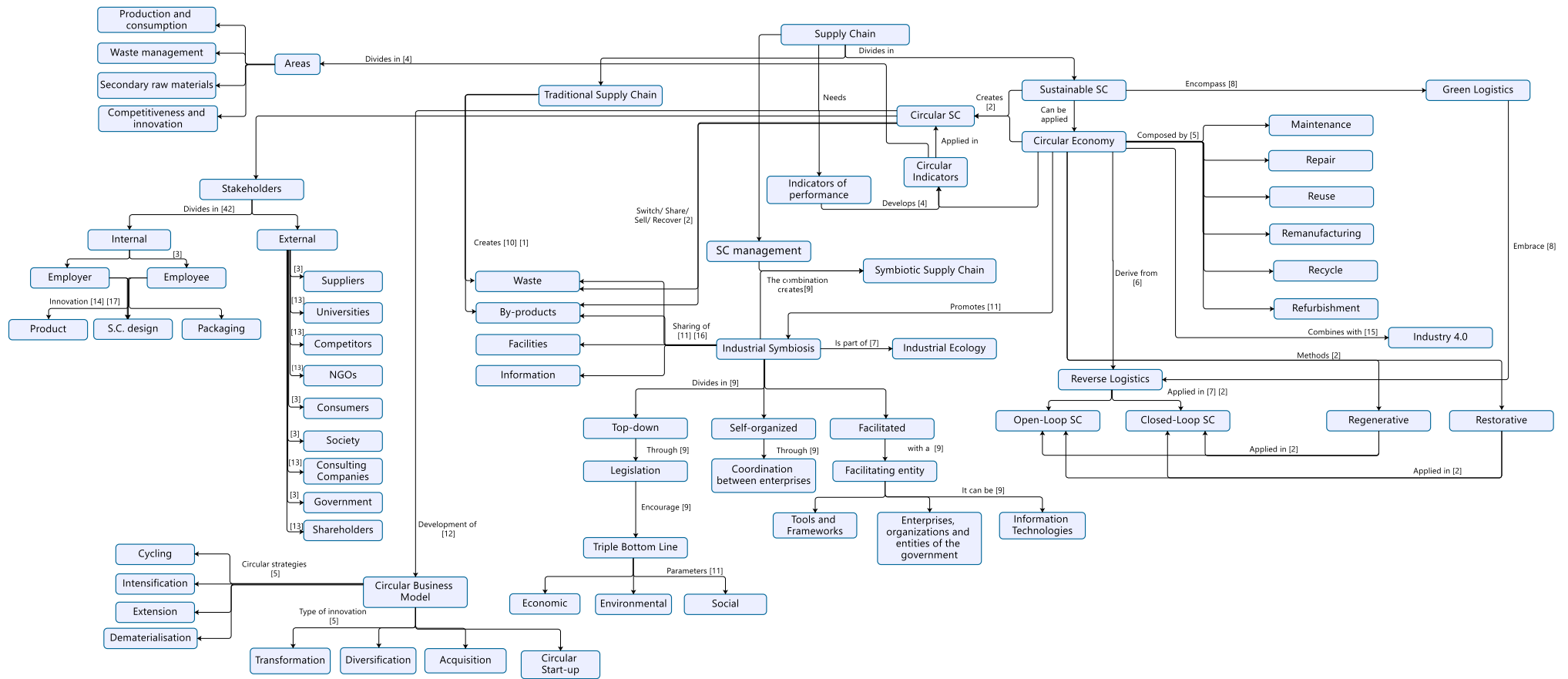


Figure 1 - Conceptual map

Source: Autor

The application of Circular Economy in supply chains is associated with both enablers and challenges in the adherence to these practices. In image 3 it is possible to observe on the left side the enablers of the Circular Supply Chain, highlighting certain practices, such as the adhesion of the chain to the Circular Economy, together with Industrial Symbiosis and Industry 4.0. And on the right side, the challenges that may be faced.

In summary, being a still little explored theme, this tool allows us to understand how to assist in the adherence to the Circular Economy. The tool facilitates the reader to understand which practices should be developed and which models should be implemented, addressing which problems may be associated with these circular practices. Having knowledge of the challenges, there is greater ease in preparing how to prevent the mentioned difficulties.

### 6.3. Recommendations

Firstly, due to the lack of knowledge regarding the Circular Economy and its application in supply chains, it is crucial that information is shared not only between companies, but also with governmental and regulatory entities, in order to facilitate the adherence to practices. For example, the author Neves et al.,(2019), stated that Portugal could develop an Industrial Symbiosis implementation plan if it used the experience gained in the Eco Industrial Park of Relvão. In addition to this, the author also concluded that, there are many cases of Industrial Symbiosis in Portugal that are not reported. The recommendation would be to try to make a survey of which companies already carry out this type of networking, understand why there is no information sharing, and try to have a knowledge transfer and collaboration in the development of an official plan for the implementation of Industrial Symbiosis in Portugal.

Another way to encourage the practices of Circular Economy and Industrial Symbiosis in Portugal is through legislation, i.e., not only making the adhesion to the practices more attractive, but also making the processes simpler, as for example, in waste management, resulting in more companies joining these networks. Besides this, in order to promote Industrial Symbiosis of the facilitated type, there could be the promotion of facilitating entities for the adhesion to the practices, resulting in a simpler process for the interested supply chains.

As far as the geographic location of Industrial Symbiosis is concerned, this should be analyzed from case to case. However, it is necessary to take into consideration that it is generally not feasible when they are applied over long distances (Herczeg et al., 2018). Since it must be considered that in addition to increasing the number of possible partners and resources, there is also a decrease in the level of sustainability of this network and an increase in costs associated with it (Herczeg et al., 2018). In this case, the recommendation is to always analyze the case in hand, considering that the lower distances, usually are the most viable in terms of sustainable development.

Also, in regard to the waste that is produced, these can be associated to certain patterns and cultures of the society to be taken into consideration, thus, in order to overcome these problems, it becomes necessary to analyze the waste

according to the region or country in question (Hamam et al., 2021). This is because, it is necessary that a collaboration between the different stakeholders occurs in order to result in more sustainable behaviors, both at the corporate and individual level (Hamam et al., 2021).

As argued in this paper, by the author Rincón-Moreno et al., (2021), the definition of tools and criteria that measure circularity is not outlined. For example, in the case of Portugal, it is a country that exports manufactured wood products, however, these products are not recycled or further treated in their country of origin (Gonçalves et al., 2021). Therefore, it is concluded that the existing indicators focus more on the production process and, in the case described, most indicators are unable to measure the level of circularity (Gonçalves et al., 2021). As a recommendation, it is suggested that there is a study and development of circular indicators that allow to evaluate the performance in a more complete and correct way, covering the supply chain in its entirety.

### 7. Conclusions

The concept of Circular Economy was created in 2010, with the creation of the Ellen MacArthur Foundation, however, after more than a decade, it is still a little explored concept when it comes to the logistics area. One of the conclusions that could be drawn from this work was the need to further investigate the theme in question, understanding how it can be applied to supply chains and how it influences the management of it.

The Circular Economy has driven paradigm shifts in supply chains, allowing the transition from a traditional and not very sustainable model to a circular model that excels in social, economic, and environmental benefits. Such a model allows not only to take advantage of by-products and waste that are created along the chain, but also to recover products to consumers when they reach their end-of-life. Hence, a Circular Supply Chain leads us to an innovation in the logistics area, which unfortunately is still little explored, as it was analyzed in the chapter 2. As such, it is necessary to develop incentives in the research and deepening of the application of Circular Economy in supply chains, not only approaching this theme in a conceptual way, but also in a more practical perspective, resulting in the development of frameworks and tools that assist in the implementation of circular measures.

The Circular Supply Chain focuses on the absence of waste, through product/service development, waste treatment, by-products, and products at their end of life (Batista et al., 2018). Being a restorative and regenerative system, it allows longer product life cycles, promoting environmental, economic, and social sustainability (Hussain & Malik, 2020). In order to enable an easier adoption of Circular Economy and Industrial Symbiosis practices in supply chains in Portugal, as Neves et al., (2019) argued, it is necessary to reduce tax rates for companies with sustainable practices, create funds to increase the amount of Industrial Symbiosis networks and disseminate the practices of companies that are already inserted in this new paradigm. Furthermore, it is recommended to create policies and strategies to encourage sustainable development and support



companies in the Industrial Symbiosis, simplify the law regarding the classification of by-products, and increase the rates of waste disposal (Neves et al., 2019). Moreover, It is crucial to share information and experience between companies so that it is possible to disseminate circular and symbiotic behaviors in a simpler and more correct way. In this way, Portugal will be able to develop a program to implement Industrial Symbiosis.

Besides this, the application of Circular Economy and Industrial Symbiosis is linked to the consumption habits of each society (Hamam et al., 2021), so each country needs to analyze its needs and create tools to support the adoption of circular practices. Thus, although Portugal needs to take into consideration the experience of other countries, it is essential to integrate the consumption habits of the Portuguese in the development of their adhesion models for companies.

In relation to Industry 4.0, it allows changes in the design of supply chains, focusing on sustainable development. As so, the logistics industry has undergone a major change thanks to the development of I4.0, since it has resulted in the change of business models and the implementation of new technologies in supply chains (Kumar et al., 2021). However, technological evolution causes negative impacts not only on the environment, due to the use of information centers and technological equipment, which require a large amount of energy and resources (Sharma et al., 2021), but also on the labor market, since it becomes necessary to lay off employees from older jobs (Dantas et al., 2021). Thus, it should be further investigated, how it is possible to mitigate this difficulty present in a Circular Supply Chain, resulting in environmentally, socially and economically sustainable development.

Through the case of the application of Circular Economy at Cisco (Cisco, 2022), it was possible to conclude that a Circular Supply Chain should take into account five principles, namely, use recycled materials in products; the standardization and modularization of components to simplify the supply chain and allow the use of circular practices; use recycled and renewable materials in packaging and accessories; improve the energy efficiency of products through intelligent energy consumption; use products with components that facilitate circular practices in disassembly, repair and reuse, resulting in a longer lifetime of products.

Throughout the work, it was possible to notice that supply chains can be strongly related to the Circular Economy, excelling in economic development, however, taking into account how this can affect the environment and analyzing how, it is possible to solve the problems that may occur. However, it should be noted that the problems in this area are not only the lack of information and research on Circular Economy applied to supply chains, but also the fact that the research work done focuses more on a conceptual approach, not addressing how to apply these practices in supply chains. Therefore, this dissertation was developed to be a tool to help understand and analyze the application of Circular Economy in supply chains, analyzing the challenges and opportunities they face in their management.

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