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How to Improve the Corporate Framework of the Portuguese Cork Industry

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Abstract

With the rising concern towards ecological problems, society is changing and starting to give more value on environmentally friendly initiatives. Consequently, the Linear Economy model is beginning to diminish, providing to Circular Economy (CE) an opportunity to emerge.

Although by nature a "*green*" industry, the Portuguese cork does not fully utilize the CE model. Thus, the purpose of this investigation is to understand if the Portuguese cork industry has the capacity implement a CE paradigm and how it could benefit the industry, by studying the possibility of incorporating a closed loop supply chain, the capability to use technologies from the fourth industrial revolution (4IR), the sustainability policies of this industry and its ability to innovate and develop new products.

To achieve a conclusion, it was analysed various findings and conducted seven interviews to people related to the Portuguese cork industry, that helped answer the Research Questions due to their feedback on several matters related to the implementation of a CE paradigm in this industry.

The results determine that, in theory, the Portuguese cork industry would benefit from a CE paradigm. The industry's policies are sustainable and it is capable to innovate and develop new products. However, the implementation would not be easy because the majority of business keep focusing on cork stoppers, there is a lack of fundings to obtain 4IR technologies and it is difficult for the industry to close the loop of the supply chain, especially to its main product, the cork stoppers.

Keywords: Circular Economy, Cork, Industry 4.0, Innovation, New Products Development, Portuguese Cork Industry, Supply Chain, Sustainability.

JEL Classification Codes: Q01 (Sustainable Development); M11 (Production Management); O13 (Agriculture • Natural Resources • Energy • Environment • Other Primary Products).

Resumo

Com o aumento do interesse em relação aos problemas ecológicos, o mundo está a mudar e a começar a dar mais valor a iniciativas amigas do ambiente. Consequentemente, o modelo da Economia Linear está a perder força, oferecendo um oportunidade à Economia Circular (CE) para emergir.

Apesar de ser uma indústria "*verde*" por natureza, a indústria portuguesa da cortiça não se enquadra por completo no modelo CE. Posto isto, esta investigação tem como objetivo a compreender se a indústria portuguesa da cortiça consegue implementar um paradigma CE e como isso iria beneficiar a indústria, estudando a possibilidade de incorporar uma cadeia de suprimento em circuito fechado, se tem a capacidade de usar tecnologias da quarta revolução industrial (4IR), as suas politicas sustentáveis e a aptidão de inovar e de desenvolver novos produtos.

Para chegar a uma conclusão, foi realizado uma análise a vários estudos e sete entrevistas a pessoas relacionadas com a indústria portuguesa da cortiça, ajudando a responder às Research Questions, comentando várias questões relacionadas com a implementação de um paradigma CE nesta indústria.

Os resultados determinaram que, em teoria, a indústria portuguesa da cortiça beneficiaria de um paradigma CE. As políticas são sustentáveis e têm capacidade de inovar e desenvolver novos produtos. No entanto, a maioria dos negócios continuam demasiado focados em rolhas, há pouco capital para investir em tecnologias 4IR e é difícil para a indústria de criar um circuito fechado na sua cadeia de suprimento, especialmente para o seu produto principal, as rolhas.

Palavras-chave: Economia Circular, Cortiça, Indústria 4.0., Inovação, Desenvolvimento de Novos Produtos, Indústria Corticeira Portuguesa, Cadeia de Suprimento, Sustentabilidade.

Códigos de Classificação JEL: Q01 (Sustainable Development); M11 (Production Management); O13 (Agriculture • Natural Resources • Energy • Environment • Other Primary Products).

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Glossary of acronyms

4IR: Fourth Industrial Revolution
APCOR: Portuguese Cork Association (Associação Portuguesa da Cortiça)
CE: Circular Economy
CEBPS: Circular Economy-Based Production Systems
EMAS: Eco-Management and Audit System
EMF: Ellen MacArthur Foundation
EU: European Union
I4.0: Industry 4.0
IoT: Internet of Things
LE: Linear Economy
NPD: New Product Development
SMEs: Small and Medium-Sized Enterprises

1. Introduction

1.1 Theme relevance

The need for an environmental, economic, and socially sustainable society, meeting the present demands without compromising the capability of future generations to meet their own needs, has a strong relevance nowadays. The socioeconomic and ecological overview, technological development, population growth and the global awareness of resource scarcity and rapid depletion are changing radically. There is a widespread perception, albeit slow, that the Planet is fragile, its ecosystems are in a delicate equilibrium and natural resources are at risk due to over-exploitation (Goyal, Esposito & Kapoor, 2018). The consumption-driven based on the "*cradle-to-grave*" model uses limited resources to create new products systematically discarded in unsustainable landfills after being used. The future risks correlated a growing population with an ever-increasing demand for limited resources, the finite resources nature, and the "*take-make-dispose*" oriented Linear Economy model generated interest in a new Cradle pattern. Consequently, the "*cradle-to-cradle*" approach is central to the idea of a Circular Economy model (Goyal, Esposito & Kapoor, 2018).

This new systemic approach to economic development has emerged as a new industrial paradigm and a solution to the LE's negative externalities (Murray et al., 2015). The CE's main objective is to decouple economic growth from resource constraints and social impacts (Merli et al., 2017). As such, the CE concept is defined as "*An initiative for sustainable development that aims to reduce linear materials and energy transfer flows in collaboration between social producers and social actors in consumer systems to promote sustainable development*" (Korhonen, Nuur, Feldmann, Birkie, 2018, p. 547).

Ideally, in the CE concept, all waste is avoided or recycled. The products are designed in such a way that materials and components can be recovered and reintroduced (in a loop) into the productive cycle, from production and consumption to reuse, repair, renovation, refurbishment, and recycling. Changing to a CE represents a paradigm shift that involves a change in mindset amongst the financial sector, policymakers, and business organizations (Korhonen, Honkasalo & Seppälä, 2018). However, the key to a successful transformation will be the collaboration between the stakeholders (Seuring & Gold, 2013).

According to da Silva, Rocha, Wienhage and Rausch (2009), the concept of sustainability is based on promoting environmental responsibility and reducing natural resources consumption

without losing any profits, which will diminish negative impacts on the environment and preserve the planet for future generations.

Thus, the CE is seen as an alternative to the traditional model of production and consumption. Its added value is its ability to face many of today's environmental challenges, drive new business opportunities and stimulate economic growth. What if we could preserve the resources already used in the economy for a more extended period and keep them at the highest economic value? It would no longer be necessary to take out and get so many raw materials, reducing waste and other environmental impacts, such as greenhouse gas emissions. We would have the capital to innovate in business models, products and services and create more jobs. This is the CE principle: the model of abundance instead of the LE's scarcity.

Portugal has a long political history of promoting resource efficiency in managing and recovering specific waste streams, energy efficiency, and green growth. Cork is one of the natural resources on which economic growth is based, and the cork sector has demonstrated a sustainable growth and has been quick to adopt new and sustainable technologies in all production processes.

Consequently, being highly dependent on natural resources, the Portuguese cork industry has an immense interest in becoming fully sustainable and building long-term resilience, generating business and economic opportunities while providing environmental and societal benefits (Demertzi, Silva, Neto, Dias & Arroja, 2016).

The global cork industry is focused on the western Mediterranean countries, with Portugal and Spain as the dominant forces (Ramos, Berzosa, Claren, Marin & Rouboa, 2019), but with Portugal in the top position, after two centuries of leadership by Spain (Sierra-Pérez, Boschmonart-Rives & Gabarrell, 2014). Approximately 85% of the global production are concentrated in the countries previously mentioned together with Italy and France (Ramos et al, 2019), due to the availability of raw material (65% of total cork oak forest) and proximity to the wine market (Sierra-Pérez et al, 2014). Some countries in North Africa, such as Tunisia, Algeria and Morocco, also have a significant percentage of total cork oak forest, around 30% altogether, but are still far behind the competition in terms of production, reaching only a total of little more than 10% combined (Pena, 2012). Nowadays, there is an increase in cork’s demand due to its environmentally friendly characteristics and the escalating importance of sustainability (Pena, 2012).

1.2 Research problem

One objective that every company desires to achieve is to fully utilise all raw materials used in the manufacturing process with a minimum of waste produced. Nevertheless, established firms generally follow mainly linear models which is a significant obstacle to the CE transition and, consequently, to resource optimisation and waste reduction. An approach to this problem lies in changes, from technologies to operations' processes and manager's mindset. To the Portuguese cork industry, the first premise - to attain sustainable use of all raw materials in the manufacturing process with a minimum of waste produced - is unquestionably applicable, especially bearing in mind the raw materials organic nature and biological origin of (the cork). *Quercus suber,* the tree from which the cork material is extracted, only survives in exact conditions regarding temperature, water, and soil characteristics. Thus, climate changes are acknowledged as a menace to the cork industry's sustainability since those variations may inflict massive damage to the cork oak forest. Therefore, the preservation of this natural resource is a core decision for sustainable use. Nonetheless, the Portuguese cork industry recyclability potential is not maximized due to:

(i) Insufficient collection points for cork products, especially stoppers.

(ii) Reduce waste use, primary because of transportation costs.

(iii) and, according to Mestre and Gil (2011), lack of processes and technological modernization.

Considering the issues above explained, a problem emerges: The scarce knowledge on how to achieve wealth-generating sustainable products and services in Portuguese cork industry in a CE framework.

1.3 Research aim and objectives

This research was intended to present a solution for implementing sustainability initiatives in cork companies' business processes, analyzing, planning, implementing, monitoring, and controlling the cork companies' current (or new) processes, making a bridge to the CE paradigm. To accomplish this target, a systematic approach has been established to achieve a state of sustainability at cork small and medium-sized entreprises. This is expected to be reached through the implementation of sustainable practices and circularity in the cork industry. This change can lead to cost reduction, waste reduction, process optimization, production of innovations, reduction of energy/water consumption, reduction of waste generation, customer satisfaction improvement, and employee turnover. The following objectives accomplished the proposed target:

1. Identify what are the current problems/barriers to implementing sustainability initiatives in cork industry;
2. Identify and critically review the current sustainability implementation frameworks found in the Portuguese Cork sector and comparing with literature;
3. Identify key persons in sustainable operations management and obtain their feedback regarding the future framework to establish or the existing framework;
4. Create a framework to effectively implement sustainability practices in SMEs in the Pt Cork Industry towards circularity in the sector;
5. Try to employ the framework in a real-world scenario and obtain the feedback.

The present proposal target research is focusing on if and how the Portuguese cork industry can shift to a more sustainable way of work by engaging in the CE paradigm. Targeting new products, and producing cleaner industrial technology, the cork industry has come to regard a reconfiguration to deliver high-quality products, competitively and cleanly.

In terms of theoretical, managerial and social outcomes, a new economic paradigm is emerging in the cork industry, pushing changes in the current extraction-production-consumption-wasting concept. Additionally, due to its diversity and production techniques, Cork is a source of innovation, boosting new product development and switching business policies. Therefore, it is a suitable topic for a master's degree dissertation in Management of Services and Technology. Furthermore, the sustainable practices used by companies towards a CE paradigm impact on people's lives and the natural environment. Hence, this study is expected to be a valuable tool for the cork industry to understand and apply potential sustainability improvements that contribute to sustainable development.

1.4 Research questions

From the problem mentioned above, two research questions arise:

- RQ1: Does a Circular Economy paradigm benefit the Portuguese cork industry?
- RQ2: Are Industry 4.0 Technologies and Digital Transition drivers for Sustainability and Circular Economy practices in the Portuguese cork sector?

1.5 Methodological approach

To collect data for this thesis, a semi-structured interview was used. Although the objective was to have at least ten interviews, only seven people agreed to join this research, from more than 50 requests to individuals, organizations and companies. The interviewed were four academic professors, two directors of a Portuguese cork company and to the director of the

Portuguese Cork Association. The questions were made after completing the Literature Review and were based on the Research Questions and research related propositions. The interview was composed by 19 questions, divided into the following four categories:

(i) Portuguese cork industry and sustainability policies.
(ii) Sustainable Portuguese cork industry in the context of I4.0.
(iii) Portuguese cork industry and the I4.0.
(iv) Cork industry and new products development.

All the interviewed had the interview previously delivered, which then had the possibility to respond to the questions via email or through an online meeting. All of the interviews were made between the months of April and July, of the year 2021.

Afterwards, the interviews were analysed and compared to understand how their opinion coincided and differed and to reach a conclusion which would help to answer the Research Questions.

1.6 Thesis structure

This thesis structure follows a traditional dissertation structure. Subsequently to the theme introduction, this paper features the literature review, which is subdivided into two primary topics: sustainability and CE; and Cork and the Cork Industry. The methodology of this thesis is the following subject, succeeded by the results presentation and discussion and, finally, the Conclusion. At the end of the paper, the bibliography will be exposed.

2. Literature review

2.1 Sustainability in today's business

According to Kuhlman and Farrington (2010), the first definition of sustainability appeared in the Brundtland Report (1987). However, the concept had already been created in forest management, in which the exploration could not be more significant to the natural forest rejuvenation. The definition presented in that report was: "*Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland Report, 1987, p. 40). Nevertheless, as Kuhlman and Farrington (2010) stated, the meaning of sustainability has changed over time. It was included a social dimension in the definition has a third pillar, with even the possibility to include a cultural and political pillar to the concept, as the Brundtland report that only mention the economic and environmental pillars. Kuhlman and Farrington (2010, p. 3442 and 3443), conclude that "*sustainability can now loosely be defined as a state of affairs where the sum of natural and man-made resources remains at least constant for the foreseeable future, in order that the well-being of future generations does not decline. Ideally, when we assess the potential impact of a proposed policy, programme or project, it should both lead to higher well-being and to a positive or at least neutral effect on the overall state of resources for the future—in which case we can speak of sustainable development*". Shrivastava (1995), reenforced the sustainable development concept by stating that sustainability offers the possibility to decrease long-term environmental issues. These problems can be associated with human activities consequences, such as pollution or resource depletion, but also integrate some economic problems, such as variations in energy costs. Starik and Kanashiro (2013), affirmed that a completely sustainable world would be capable of fostering even more humans and to sustain all other species, nevertheless, to achieve this, an enormous change in human habits must occur.

Nowadays, there are several factors driving businesses into investing in sustainable organizational structures and practices, which can be related to the sustainability revolution, a movement of economic and social dimensions, with the goal to make human activities more sustainable, minimizing the impact on future generations. (Starik & Kanashiro, 2013). Some of those factors may be the social pressure made by consumers, employees, investors and activists about how companies must approach environmental problems (Gardiner & Thompson, 2017) and public policies that obligate or forbid some business activities towards ecosystems (Abbott, 2012). This premise is strengthened by Genovese, Acquaye, Figueroa and Koh, 2015, by stating that, nowadays, sustainable policies in the supply chain are gaining importance due to

company's increasing responsibility on environmental and social. Those companies realize the importance of the relationship between financial goals and social and environmental goals, and are managing sustainability to improve processes, pursue growth, and add value to their business rather than focusing on reputation alone. Additionally, a sustainable supply chain may be another source of competitive advantage for companies (Genovese et al., 2015).

2.2 Circular Economy

2.2.1 Environmental problems and Linear Economy

Kottaridou & Bofylatos (2019) stated that since the sixteen century society has abused the environment to achieve economic development, seeing it has a provider of unlimited resources and with an endless room for our waste, which, according to Genovese and her colleagues (2015), had severe repercussions for the ecosystem. With a global population of nearly 8 billion people whose necessities and desires keep increasing, it has never been more critical to ensure natural resources availability by changing to sustainable industrial practices (Mhatre, Panchal, Singh and Bibyan, 2020). Nowadays, human activities are requiring the equivalent of 1.7 planets Earth to satisfy production and consumption. Nonetheless, if nothing is changed, and the linear model continues to be implemented, by 2050, three planet Earths will be needed (World Economic Forum, 2019). Several studies indicate that Earth possesses a finite quantity of resources; thus, the need to utilize these resources optimally increases manifold two thereof (Galli et al. 2019; Mhatre et al., 2020). As stated by Starik and Kanashiro (2013), although this is a frightening situation, it should not be a surprise for most people because all pillars of human society continue to be highly dependent on the environment. These problems substantially escalate the importance of implementing a sustainable model in our society and economy. Those models could be based on CE, which minimizes the impact on the environment from human activities by reusing raw materials and utilizing ones that are not harmful (Genovese et al, 2015).

By operating with a "*cradle-to-grave*" model, the business will acquire the raw materials, transform it into finished goods and sell it to the consumer, who will eventually discard the product, turning it into waste (Ghisellini, Ripa & Ulgiati, 2018). Thus, generating an enormous quantity of waste, which pollutes the environment and exhausts natural resources due to lack of sustainable practices, such as recycling (Genovese et al, 2015). The LE's primary supposition is that there are infinite materials available to use, which makes business negligent and careless about waste production with no concerns about the depletion of resources (Goyal, Esposito & Kapoor, 2018). As reenforced by Kottaridou and Bofylatos (2019), the use of this linear model

created a culture of waste creation in every step of a product's lifecycle, from even the bought of the virgin raw materials, passing through its manufacturing, until their disposal as a used product. The linear paradigm of *take-make-dispose* in production and consumption patterns impedes global sustainability goals achievement (Sopjani et al, 2020). Given all the new technology in their power, humans have a unique opportunity to achieve the "*cradle-to-cradle*" model by changing materials and guiding society away from antiquated methods. However, the sole strength of technology is not enough to solve all problems (World Economic Forum, 2019).

2.2.2 A new path: from Linear to Circular Economy

In the business world, efficiency has been consistently misinterpreted as cost-cutting while increasing production. However, now, to create a sustainable development of the economy, it needs to imitate nature's efficiency in resource management (Aras & Crowther, 2009). The change from the LE into the CE is ever more important to decrease the impact of human activities in the environment (Upadhayay, & Alqassimi, 2019). It is essential that this change happens at all levels, obtaining maximum value from the supply chains, based on four premises: (i) CE design; (ii) new business models; (iii) reverse logistics; and (iv) government support. These requirements may create new job opportunities, increase competitiveness between companies and accelerate sustainable economic development (Daou et al., 2019). Nowadays the awareness of companies in resource exploration and process efficiency is rising, affecting different stages of their value chain, and promoting the CE principles mentioned before (EMF, 2020).

This economic model promotes minimization or complete elimination of waste and pollution. Also, the maximization of goods and raw materials utilization and regeneration of natural systems are addressed (EMF, 2020). CE enables this by investing in the reverse logistic and sharing economy, helping companies to reuse, recycle and remanufacturing resources that would go to waste (Upadhayay & Alqassimi, 2019). As mentioned by Kottaridou and Bofylatos (2019, p. 2), "*Circular Economy, as an approach to Sustainability, offers efficient and realistic solutions to these problems (pollution and waste) paving the transition from the current 'take-make-waste' extractive industrial and economic model, to a circular one*". Nevertheless, according to Sariatli (2017), the increasing utilization of waste would not only benefit the environment. Still, it would also be an economic advantage due to the closed-loop processes, which would reduce price fluctuations and increase efficiency in using resources.

2.2.3 Circular Economy definition and principles

Nowadays, it is becoming increasingly important for firms to modify their operational behaviour to become more sustainable, from an economic, environmental and social point of

view (Nosratabadi et al., 2019). By proposing a reform to the entire industrial system, including the production process and the consumption in the supply chain activities, CE is emerging as a sustainable development strategy to the global economy (Sehnem et al, 2019). According to Sehnem and colleagues (2019), there are two different CE cycles. One of them is the biological cycle, which focuses on rebuilding ecosystems, such as reducing natural materials extraction, utilizing renewable materials and energy and utilizing waste. The other is the technical cycle, which focuses on increasing the products life cycle through several actions, such as maintenance or recycling.

A circular business model is a new type of business model, which is considered a subsection of sustainable business models (Rosa, Sassanelli & Terzi, 2019). The three main characteristics that characterize a CE business model are: (i) closing of raw materials chains; (ii) a transition from ownership to the provision of services; and (iii) an increase of intensity in product utilization. The CE models must be based on closing loops, generating multiple values, selecting the best strategy, constructing a firm that fits with organizing between parties and establish circular earnings models (Rogge & Reichardt, 2016). Moreover, according to Ashby (2018), recovering value from used products through a closed-loop of reuse and renovation would increase both economic and environmental performance, is the main CE principle. However, it would be needed a redesign of products, manufacturing procedures and supply chains to keep resources flowing in that closed loop and reduce waste. In terms of redesigning products, according to Mestre and Vogtlander (2012), sustainable product design is a process that enables NPD solutions with high value to the customer and society. Also, it facilitates the incorporation of eco-efficient aspects into the new product solutions (also called eco-design), thus signifying an essential contribution towards lessening the environmental impact of products. In this part of the production, resources and processes are considered (including the recycling procedures), to become more eco-efficient by upgrading the use of resources and waste and reducing emissions. Thus, it is estimated that around three quarters of the environmental impact of any product is determined on this stage, representing by far the most important stage to increase the sustainability of a product (Mestre & Gil, 2011). Completely natural, biodegradable, reusable and recyclable, cork is perfectly aligned with the environmental awareness of contemporary society and is tough enough to circulate repeatedly in the economy.

2.2.4 Circular Economy in the EU

In the late 21st century, the European Union began to address the environmental problem, explained previously in chapter 2.1, due to the social pressure (Ghisellini et al., 2018), by introducing the Eco-Management and Audit System (EMAS), with the objective to increase

sustainable business. This initiative allowed the companies to evaluate its environmental performance and, if they were able to maintain or become certified, the company could display the EMAS logo and receive market benefits (Abbott, 2012). Additionally, at the turn of the century, the EU implemented the Landfill Directive (1999/31/ec), stating that the member states should reduce the total waste sent to a landfill to less than 35% of the total of 1995. Later, the EU imposed the Waste Directive (2008/98/ec), with the zero waste goal, proposing to eliminate all landfill activities until 2020, supported by taxes, bans and regulations (Ghisellini et al., 2018). According to Ramos et al (2019), this directive determined the hierarchy for waste management as: first, prevention, then reusing, followed by recycling, recovery and the last option being disposal. Furthermore, according to Mhatre et al. (2020), the EU adopted a project called Circular Economy Action Plan (CEAP), in 2015, with the objective of transforming its LE into a CE. This project will prioritize closing the loop of products by increasing recycle and reuse practices (Antikainen & Valkoraki, 2016), developing optimal business models supported by sustainability, innovation and job creation, escalating a connection between the environment and the economy (Mhatre et al., 2020). To execute its plan of creating a CE, the EU focused on the five key approaches to implement circular business: (i) Circular supplies; (ii) Resource recovery; (iii) Product life extension; (iv) Sharing platforms; and (iv) Product as a service (Mhatre et al., 2020).

The realization of these programs becomes especially important for the EU member states due to being highly dependent on imported raw materials. Since the EU produces every year 2,5 billion tons of waste, with 60% of solid waste sent to landfill or incinerated and the rest recycled or reused, which translates to an enormous amount of natural resources lost but, also, to an enormous opportunity for the EU (Ramos et al, 2019).

2.2.5 Circular Economy and industry 4.0

As mentioned by Upadhayay and Alqassimi (2019) and Rosa et al (2019), technology development is a vital element for a successful CE, especially technology that facilitates sharing information and connection. At the moment, technology is integrating our society at an extraordinary speed and scale, such as artificial intelligence (AI), 3D printing and industrial robots that combine the digital and the physical world, being the core of the Fourth Industrial Revolution (World Economic Forum, 2019). These technological advances allow companies and governments to accelerate the implementation of a circular model (Upadhayay & Alqassimi, 2019). The 4IR, also known as the I4.0, is characterized by the introduction of new technologies capable of automation and data exchange in manufacturing processes, through connecting

cyber-physical systems, the Internet of Things, smart factories and cloud computing to the physical world (da Silva & Almeida, 2020), as shown in the figure below.

Some applications of these technologies, according to World Economic Forum (2019), are:

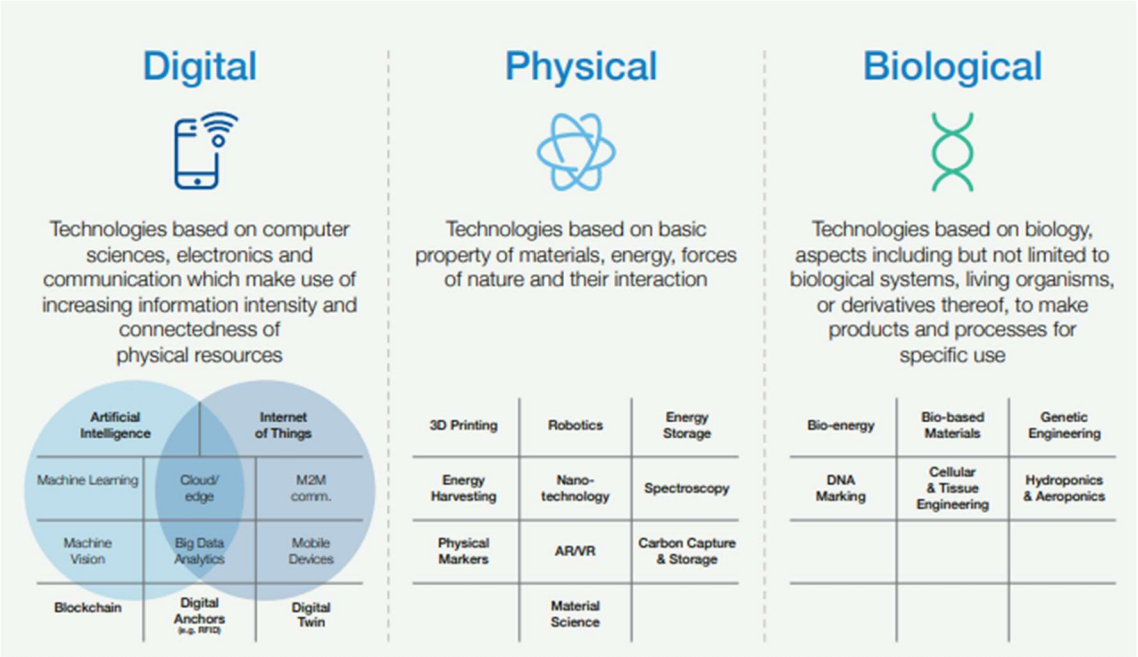

Figure 2.1 Fourth Industrial Revolution technologies (Source: WEF, 2019)

(i) Digital passport of a product, that would give access to the product's materials, how it was assembled, its current condition, its origin, optimal recycling solutions and how it can be repair and dismantle, to facilitate waste management.

(ii) Hyper-intelligent robots capable to dismantle used products and separate its materials, to ensure proper recycle and reuse the resources.

(iii) Service-based models, used by manufactures, capable of keeping track of product condition to offer repair or upgrade solutions and extend the product life cycle.

(iv) An AI-based system to support materials choices, based on the available recycled resources on that specific region and considering the recycle and reuse infrastructures of the target market, that could evaluate each product circularity qualities given a specific market, based on a KPI system, and be connected with other systems, learn from each decision and improve its suggestions.

(v) And a digital waste management system, capable to oversee household and business waste production, be connected to garbage containers and have vehicles capable to track the containers capacity, that would increase the efficiency of the collection process.

The primary challenges in this paradigm would be the lack of knowledge to apply these technologies properly and the capability to confirm confidentiality and anonymity to mitigate antitrust sentiments (World Economic Forum, 2019).

2.2.6 Circular Economy and Business Processes

According to Dumas, La Rosa, Mendling and Reijers (2018), business processes are categorized as fundamental assets of a company, which determines functions and responsibilities, having a direct impact in performance, leading the authors to state that: "*Processes are the arterial system within organisations and inter-organizational supply networks*" (p. VI). Nowadays, the increasing importance of globalization, sustainability, innovation, technology and efficiency, lead to the company's processes management importance to increase as well, due to its rule to determine the capability an organization must adapt. Thus, the way a firm designs and performs its processes will influence the service quality and may be a source of advantage. Consequently, Dumas et al. (2018), identifies five tools a company may use to assist its process management:

1. Total Quality Management – A tool primarily used in manufacturing domains, its focus relies on continuously improving the quality of products and services.
2. Operations Management – Traditionally used in controlling and upgrading the efficiency of already existing processes, with an emphasis to production and manufacturing.
3. Lean – Developed by Toyota manufacturing industry, the priority of this tool is on eliminating activities with no value.
4. Six Sigma – Created by Motorola engineering and production division, its main characteristic is on minimizing errors, with a focus on measuring the quality of output processes and comparing it with the outputs of previous procedures.
5. Business Process Management – This tool focuses on analysing, redesigning and improving the entire chain of events, instead of singular activities, by overseeing how an organization performs, to guarantee consistent outcomes and exploit improvement opportunities.

Although these tools were developed in different circumstances and in different times, some share identical premises and even may be used cooperatively.

2.2.7 Circular Economy SWOT

To summarize the economic and social benefits and disadvantages brought by the CE paradigm, the following SWOT analysis, based on Sariatli's work (2017), was designed:

INTERNAL FACTORS	
STRENGTHS (+)	**WEAKNESSES (-)**
Reduction of raw-material cost and dependence, on account of making use of waste created. Increase in the durability of products, by integrating Circular Economy mindset in R&D. Mitigation of price fluctuations due to closed-loop processes. Improve efficiency on resource management.	Requires coordination of all stages of the value chain. It does not exist an organization or guideline to help implement it. Demands a learning period for companies and customers to be implemented. Still, it is lacking investment and statal help.
EXTERNAL FACTORS	
OPPORTUNITIES (+)	**THREATS (-)**
The proper use of materials and waste may help companies save money (it is estimated that in the European Union it would be possible to save 600 billion USD/year). Creation of new jobs specialized on creating, maintaining, or improving Circular Economy solutions and jobs destined to support Circular Economy activities.	Risk of monopoly-like situations if a company would control the entire life cycle of a product. Due to the intense collaboration and process sharing, it may create tension between companies if they are not completely honest.

Table 2.1. Circular Economy SWOT analysis (Source: Sariatli, 2017)

This SWOT analysis enables to conclude that a CE paradigm will not only assist the environmental, but also has much to offer to the world economy. However, it is crucial to increase the investment in this new paradigm and create rules to prevent monopoly and dishonest competition situations.

2.3 Circular Economy and business

2.3.1 Closed-Loop supply chain

The authors Antikainen and Valkoraki (2016, p. 6) stated that "*Closing material loops often affects concerning products or services, relationships with customers and partners, and different production processes and revenue models*". This sentence summarizes the impact a circular supply chain implementation would have in the current linear models. The application of a reverse supply chain to enable the introduction of used resources to re-enter the forward supply chain and, thus, closing the loop, would obligate several businesses to redesign itself and allow new players to enter the market and take advantage of this new era of circular business models. Furthermore, closing the loop would require companies to open themselves and communicate, coordinate and collaborate with other businesses to achieve a more efficient closed system, instead of each enterprise creating internal loops. These relationships would create a "*win-win*"

situations for the several businesses that included and facilitate the implementation of each circular business model (Antikainen & Valkoraki, 2016).

There are two methods to design a closed-loop supply chain:

Circular Economy-Based Production Systems (CEBPS)

Sehnem and her colleagues (2019, p. 238) mentioned that "*Circular economy-based production systems and excellence of sustainable operations are methods developed by organisations to increase material circularity, optimise natural resources and system longevity. (…) CEBPS constitutes a systematic thinking approach, developing, and creating products, they adopt the premises of the circular economy from the prototype/design phase and manage the critical materials*". The same authors (2019), stated that CEBPS implements a different process for the entire value chain of industry to minimize resource usage, enlarge the lifecycle of products and eliminate as much as possible actions that harm the environment, such as waste creation. To implement a CEBPS, it is imperative to establish various laws and regulations for the government, businesses, and the society. Furthermore, there must be a steady job in inspecting industrial and social dimensions related to the CE.

Circular Economy Butterfly Diagram

To visualise the best way to change the manufacturing processes and sustainably run them across the whole supply chain is to draw the connections amongst all the stakeholders and show the continuous flow of materials in a logic and lean diagram that considers the entire life cycle of a product.

The Butterfly Diagram (Figure 2.2) was conceived to recognize the necessity of detailing the life-cycle of a given product. In this diagram, the central section represents the "*cradle-to-grave*" model, and the rest demonstrates the continuous flow of reusing and recycling resources. The value that the product preserves is inversely related to the cycle's size, the smaller the cycle, the higher value the product maintains. "*Products are redesigned in a way that lasts longer through circular processes such as maintenance, repair, remanufacture, recycle or biochemical feedstock, cascading, anaerobic digestion, composting*" (Kottaridou & Bofylatos, 2019, p. 3).

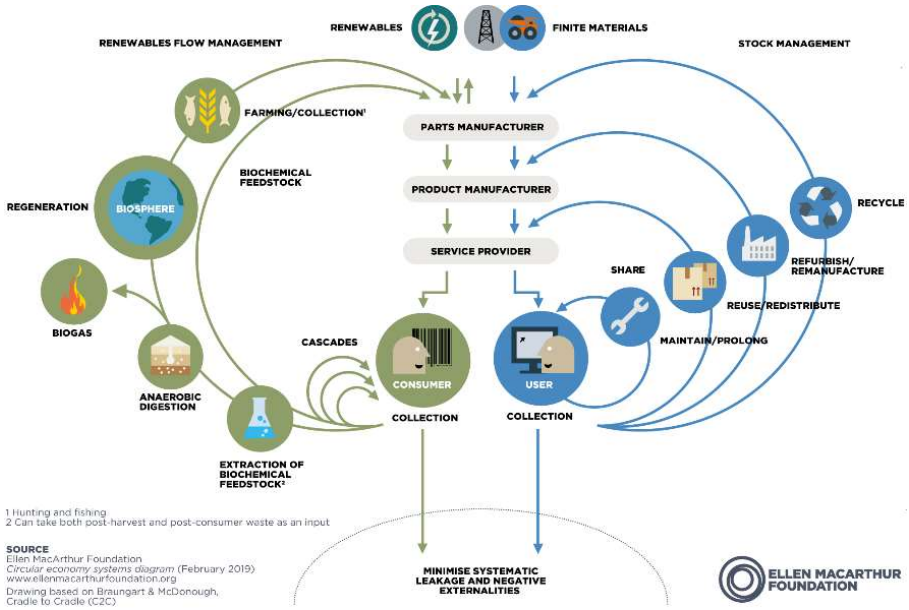

Figure 2.2. The Butterfly Diagram for Circular Economy (Source: Ellen MacArthur Foundation,

According to the EMF (2013), the Butterfly Diagram's prime contribution (Figure 2.2) supports the analysis of a specific industry's value chain by acknowledging the weak spots of the product's entire life cycle. By this way, it may be easier to shift from LE into CE and implement its three fundamental principles: (i) Design out waste and pollution; (ii) Keep products and materials in use; And (iii) regenerate natural systems.

Therefore, the CE is an economy built from a system of social production/consumption that maximizes the services created from a linear nature-society-nature flow of material and energy. This maximization happens through cyclical material flows, renewable energy sources and cascading energy flows. A successful CE contributes to all three dimensions of sustainable development: Economic, Social and Environmental. The CE regulates the flow of production to a level that nature allows and uses the ecosystem cycles in economic cycles considering their natural reproduction rates.

2.3.2 Circular business models

There are two primary methods to help a company implement a circular business model:

EcoCanvas

The EcoCanvas is a tool developed based on the Business Model Canvas with the intention to assist companies that wish to create a more sustainable business (Antikainen & Valkoraki, 2016). The primary change of this new tool relies on the implementation of social and environmental elements (Daou et al, 2019). Nevertheless, since several authors tend to develop it with different approaches, the EcoCanvas is not yet standardized (Rosa, Sassanelli & Terzi,

2019). The EcoCanvas features the four main focus from the Business Model Canvas (customers, offer, infrastructure and financial viability) and, generally, the original nine blocks from the Business Model Canvas (Daou et al, 2019), with some alterations to the blocks and the inclusion of new ones, depending on the author (Rosa et al, 2019).

ReSOLVE

This instrument subdivides itself into six different sector:

1. Regenerate – Prioritize renewable resources and energy, while restoring the environment.
2. Share – Share resources, reduce waste by utilizing used products and increase product's maintenance and durability.
3. Optimize – Improve resource management, upgrade product's quality and automate processes.
4. Loop – Remanufacture resources, recycle waste and used products and remove waste that may contaminate the environment.
5. Virtualise – Prioritise electronic greener solutions (e.g., e-books vs books).
6. Exchange – Shift to new, more advanced and greener solutions (products and services).

The ReSOLVE framework is a tool developed by the Ellen MacArthur Foundation (2015) to help firms and governments to implement circular practices.

2.3.3 Circular businesses: benefits, approaches, and challenges

After analysing the CE concept, it is possible to summarize its benefits, approaches and challenges.

Benefits

The main competitive advantage for a company brought by CE is related to NPD (innovation) and increased resource efficiency (Mhatre et al, 2020). Ghisellini and her partners (2018), consider defining CE as a method to create an economic pattern focused on appropriate use, reuse, and exchange of resources to improve production efficiency. Furthermore, this method may also decrease the adverse effects of natural resource price, thus reducing natural resources dependence for those industries, such as the Portuguese cork industry. Additionally, a firm can also create an eco-industrial park with others, allowing enterprises to reduce material and energy consumption, have lower costs for raw materials and minimize treatment costs. Nevertheless, some CE principles are more related to environmental efficiency than economic

one (Ghisellini et al., 2018). For example, the benefits of recycling decline after it reaches a certain point where it becomes overly expensive and no longer provides any net benefit.

Furthermore, as mentioned previously in chapter 2.2 of this report, and reinforced by da Silva and colleagues (2009), an additional competitive advantage created by implementing the CE method is how the consumers and investors may consider the company. Due to the increasing awareness of climate changes and other consequences from human behavior, there has been an escalating social pressure for companies and governments to become more sustainable, which means that a company that implements CE techniques may overshadow its competitors. Additionally, by becoming more environmentally sustainable, a firm is more likely to ensure its business at medium or long term, mainly if its core products depend on natural resources, such as the Portuguese cork industry.

Adopting the CE system may create an economic benefit. The "*cradle-to-cradle*" principles will impact the environment by reducing waste management problems and pollution problems for the society. Moreover, it may also increase job opportunities (EMF, 2013), because the activities related to reusing and remanufacturing are labour intensive, instead of resource intensive, thus creating a new industry and, subsequently, various job opportunities (Ghisellini et al., 2018). By investing the CE principles in transportation, in food and in civil engineering industries, there is the possibility of generating more than 300 billion euros/year, in the EU alone (Mhatre et al., 2020).

Approaches

There are five primary approaches to create a circular business:

1. Circular supplies – Reduce the demand, and thereby the extraction of virgin resources, and generate value from used products, by increasing the utilization of renewable, biobased and recovered materials.
2. Resource recovery – Recover from used products all materials that can be used and reduce the waste disposal. Although it is essential to invest strongly in infrastructures, it would also be a source of economic opportunities and job creation due to requiring extensive labour.
3. Product life extension – Improving the quality of products and the quality of repairing and maintenance services to decrease the necessity of creating new products, based on virgin raw materials.

4. Sharing platforms – By creating a connection between different companies and industries with the objective to make use of excessive raw materials, deformed products and waste originated between them.
5. Product as a service – A product is used to deliver a service, in which, instead of acquiring a product, the client would lease it or subscribe to a range of services offered by the manufacturer.

Challenges

According to Sehnem et al. (2019), there are three main obstacles for companies to implement CE strategies:

1. The first one is attrition within the firm itself, when negotiating the modifications with the stakeholders.
2. The second one is related to the technology available and affordable for the company, which is essential for redesigning the products.
3. The last one is the lack of collaboration between enterprises that may refuse to share their manufacturing process details.

This collaboration between industries would facilitate the transition from a linear system into a closed-loop one, by transforming a particular company waste into something that another may use, reducing pollution and energy consumption (Sehnem et al., 2019). The World Economic Forum (2019), gave this classification:

1. Opaque value chains, which is essential due to impacting the whole value chain and complicating the recycling and reusing stages, sabotaging waste management.
2. Linear product design is established, due to designers and companies being more interested in low-cost and high performance. There is a flawed vision of alternative materials with less harm to the environment.
3. Linear lock-in, due to lack of experts and instruments to determine the value of a used product.
4. Inefficient waste collection and reverse logistics. This situation mainly occurs in developing countries due to low investment in infrastructures that facilitate waste management and reutilization.
5. Insufficient sorting and pre-processing infrastructures, lacking material standardization, cross-contaminated courses and difficulties in adequately separating the waste (which is an expensive process) and with not enough investments to enable economies of scale.

This analysis accords with the previously stated by Sehnem and co-workers, but improves the clarification by reclassifying it into five groups, as mentioned above.

2.4 Cork and cork industry

2.4.1 Overview of cork resource: from forest to sustainable raw material

Cork is a subereous parenchyma originated by the subero-felodermic meristem of the cork tree (*Quercus suber L*.), constituting its lining trunk and branches. Cork is extracted from cork oak's trunk and branches, in semi semi-tubular forms, usually in the summer, and with a legal minimum of 9-year frequency (Gil, 2012). Since each tree has a lifespan of 150 to 200 years, it is possible to extract between thirteen to eighteen times, even without chemical herbicides, fertilizers or irrigations. In Portugal, the cork oak forests are legally protected and there are incentives for exploration (Mestre & Vogtlander, 2012).

Cork is a material with known applications since ancient times, especially as a floating and sealant object, with a soaring expansion market in the of the 20º century, due to the diversify clusters based on the cork (Gil, 2012), as confirmed by Dias and her colleagues (2014) when stating that, depending on the quality, cork can be used in several different industries, such as in fashion, construction and sports, to name a few.

The longevity of cork forests and the cork production are the two factors that significantly impact the cork value chain, a non-wood product formed in a multifunctional ecosystem that offers many products and services. The trees have an outer bark, or cork, characterized by its elasticity, impermeability and good thermal insulation (Pereira, 2016). Cork extraction is a sustainable process because it does not damage the tree and, following the extraction, new bark regrows. This process occurs every 9–14 years. (Gil, 2012). According to Dias et al. (2014), cork oak (*Quercus suber*) forests are an excellent example of balanced conservation and development to the world, by playing a significant part in the environmental processes such as water retention, soil conservation and carbon storage. Furthermore, the simple exploration of the cork oak (*Quercus suber*) significantly influences the environment due to the amount of CO2 that cork retains (Gil, 2012). Besides, if well explored, the cork oak will produce up to fourfold of cork that would be produced without any exploration, increasing, even more, the amount of CO2 retained by each tree. Another sustainable feature of cork is the ability to sustain temperatures within the -20 degrees Celsius and 90 degrees Celsius interval without any degradation, deformation or irreversible changes to properties, and with a high isolation capability, allowing the building owner to not use as much energy in heating or cooling. Furthermore, cork is an extremely durable material, an important and useful characteristic for civil engineering, as a pavement for

example, lasting more than sixty years. Furthermore, if suffering intensive use, only needs periodic maintenance. This attribute can be considered as a sustainable one because there is no need to replace the original material used with a new one, thus minimizing the waste to maintenance. Additionally, since in some cases the buildings with floors paved with cork are demolished before the cork has reached its end-of-life cycle, the material can be removed before demolition and reused for similar or other applications. These characteristics make the eco value cost of cork superior to many other resources (Mestre & Gil, 2011).

Nevertheless, because of ecological and social changes, oak forests are now threatened. To mitigate these threats, it is necessary to face future environmental and demand challenges through innovation and knowledge, such as implementing CE methods, and increase the efficiency of cork utilization to ultimately alleviate resource management of the cork industry.

2.4.2 Circularity in cork industry

The cork industry has a unique characteristic of using every cork waste in cork's transformation process because it is possible to utilise both left-overs and unused material from other operations, in a new manufacturing process. Moreover, at the end of its life cycle, if the cork made product cannot be reused, it can be fragmented into a granule that permits companies to include it into some of their transformation processes (Gil, 2012). Those qualities permit the sector to be practically waste-free, with the possibility to create a closed life cycle, if it can upgrade its recycling process to fully utilize the leftovers in the production process (Mestre & Gil, 2011). An example of cork's sustainable characteristics is that the waste from the diverse processes can be used for energy generation, reducing, or maybe even eliminating the need of non-renewable sources of energy (Gil, 2012). This ability fits for some activities, such as cork stoppers production, having a positive impact on the environment. For example, the amount of carbon dioxide originated from aluminium stoppers and synthetic stoppers manufacturing is, respectively, twenty-four times and ten times higher, if compared to cork stoppers (APCOR, 2019). According to Ramos et al. (2019), the primary sources of cork waste are:

1. Waste created during the extraction process.
2. Defective products during production.
3. Used products (around 30% are transformed into other products and the rest is triturated).

The sources of waste previously mentioned represent the primary challenges for the cork industry. According to Mestre and Gil (2011), and confirmed by Ramos et al. (2019), this sector has difficulties to recover used products, especially in the cork stoppers sector, in which the

majority of products are never recycled due to lack of collection points. Furthermore, approximately 30% of the triturated material are sent to a landfill, instead of being used, primarily due to higher costs of delivering it to a factory that can use it. This is also a common procedure to some of the 1% of defective cork stoppers. Although the firms in the cork industry recognize cork's recyclability characteristics, it is estimated that 40% to 70% of cork waste is never used (Ramos et al., 2019).

2.4.3 Innovation in the Portuguese cork industry

In the past century, the Portuguese cork industry was very dependent on the wine sector and raw material exports. However, the appearance of synthetic materials, that could substitute cork products, forced the Portuguese cork industry to innovate, diversify and seek new industries (Pereira, 2016). In the final decades of the late century, the Portuguese cork industry started to engage in several Research and Development (R&D) activities (Sierra-Pérez et al, 2014). To complete these projects of diversification and modernization the cork industry needed, technology began to have an important role (Pena, 2012). This resulted in a decreasing dependence on cork stoppers and raw materials exports, the appearance of others market, such as civil engineering, that currently makes for around one quarter of total exports, and the transformation of the industry into the world leader in cork related R&D (Sierra-Pérez et al, 2014). Cork's potential extends to other areas, such as transports, fashion, furniture or lighting, with cork's agglomerates and by-products having exceptional potential and the capability of transforming used products or waste into several new applications (Sierra-Pérez et al, 2014). The cork sector innovation process is strongly related to the environmentally friendly features of cork, taking advantage of the increasing importance of sustainability in modern society (Pereira, 2016). Furthermore, in the building sector, the innovation process was in great harmony with European strategic plans to decrease environmental impacts and energy consumption (Sierra-Pérez et al, 2014)

Nevertheless, according to Mestre and Gil (2011, p. 61), "*The cork industry has a large technological capacity in terms of materials and processes, but this capacity is completely focused on traditional products and applications, which in the majority of the cases no longer represent competitiveness and differentiation*". This means that, although there exists an elevated investment in R&D and, consequently, a great number of patent registration, the industry does not take full advantage of the new technologies and processes created (Mestre & Gil, 2011).

2.4.4 Circular production processes in cork industry

According to Mestre and Gil (2011) and Ramos et al (2019), the production processes in the Portuguese cork industry are more oriented to a "*Zero-Waste Manufacturing*" paradigm, instead of a CE one. To achieve this strategy, there are four primary uses of cork waste, to support waste management and reduce landfilling:

1. Gasification – Capable of using any type of waste to create energy and deeply related to the EU Waste Management Directive's. This method generates clean energy and enables the industry to move away from the fossil fuel paradigm.
2. Regranulates – Fabricated based on expanded agglomerate waste, its primary utilization is related with building construction.
3. Cork Powder – Originated from residues of the industrial transformation of cork, can be used for energy creation, for medical purposes and to create cork-polymer, a composite with thermoplastics used in building construction.
4. Granulating – Created based on cork stoppers residues and waste generated from low quality cork, it is mainly used for building construction and agglomerates, such as agglomerate of cork powder without addition of glues, that can be used to develop several products, and agglomerate composite with natural or synthetic resins, also known as white agglomerate, is one of the most used products, that can be used in building construction, home furniture and space and transport industry.

However, this model does not foresee any post-use process, which generates a weakness to the Portuguese cork industry due to its difficulty to recycle used products.

3. Conceptual framework

3.1 Literature review summary

The LE, a theory based on a "*cradle-to-grave*" paradigm, is the current model used worldwide. However, with the increasing environmental issues, a new and more sustainable model was developed, named CE. This model opposes the Linear model and mitigates environmental problems by simply creating a loop in a products life cycle and transforming the "*cradle-to-grave*" paradigm into a "*cradle-to-cradle*" paradigm. Furthermore, there would be several economic and social benefits when choosing this model, due to the new opportunities, new jobs, new business models, new products and new companies that could be created to support this new paradigm.

Following the CE rise is the 4IR, or the I4.0. This I4.0 could assist governments, industries and companies to reach the circular model because of the new technologies brought by this revolution, such as the IoT, artificial intelligence, 3D printing and new industrial robots, that could be use in several manners in order to help the economy, the society and the environment. For example, one of those applications are the hyper-intelligent robots able to disassemble used products, thus, improving reusing and recycling.

The Portuguese cork industry is an ancient sector in Portugal and the world leader. Due to Portugal's unique geography, this industry has at their disposal the greatest cork oak forest in the world. However, due to cork oak's slow growth and slow outer bark replacement, the industry needs to find new ways to increase the availability of raw material. Thus, a circular paradigm could help this industry to retrieve used cork due to its "*cradle-to-cradle*" model, with assistance of the technologies of the I4.0, such as the hyper-intelligent robots previously mentioned.

3.2 Conceptual framework

In this paper, it will be analysed the Portuguese cork industry capability and necessity to adjust its sustainability politics to the CE paradigm. Thus, the CE model and the Portuguese cork industry capacity to implement its principles will be the independent and dependent variables, respectively. Furthermore, some moderating variables, such as the industry's capacity to introduce 4IR technologies, its capability to implement a close-looped supply chain, its ability to develop new products and its current status regarding sustainability policies will examined to help evaluate the Portuguese cork industry current sustainable development, compare its policies to CE principles and reach a conclusion of what may be improved.

Considering the problem and the research questions addressed in this work (section 1.4), after a literature review, some RQ-related propositions were defined, as it is presented in the Table 3.1:

RQ1: Does a Circular Economy paradigm benefit the Portuguese cork industry?	RQ2: Are I4.0 Technologies and Digital Transition drivers for Sustainability and Circular Economy practices in the Portuguese cork sector?
P1.1: The sustainability policies in the Portuguese cork industry are already fully related to the Circular Economy paradigm. P1.2: The Portuguese cork industry benefits from a Circular Economy paradigm. P1.3: The Portuguese cork industry benefits from a closed-looped value chain and from reusing and recycling materials P1.4: The Portuguese cork industry benefits from new product development.	P2.1: The Portuguese cork industry uses I4.0 technologies. P2.2: The I4.0 Technologies are drivers for Sustainability and Circular Economy practices in the Portuguese cork sector. P2.3: The drivers and hampers to introduce I4.0 technologies in the Portuguese cork industry are political, social and/or economic. P2.4: A change towards a Circular Economy paradigm, using I4.0 technologies, benefits the Portuguese cork industry.

Table 3.1. Research Questions and propositions

These eight propositions have a key role for this dissertation, by giving a support to the conclusions reached in the end, to each research questions. Each research questions has four related propositions. These propositions also serve as a base for the literature review and the interviews.

The model used in this investigation is represented in Figure 3.1:

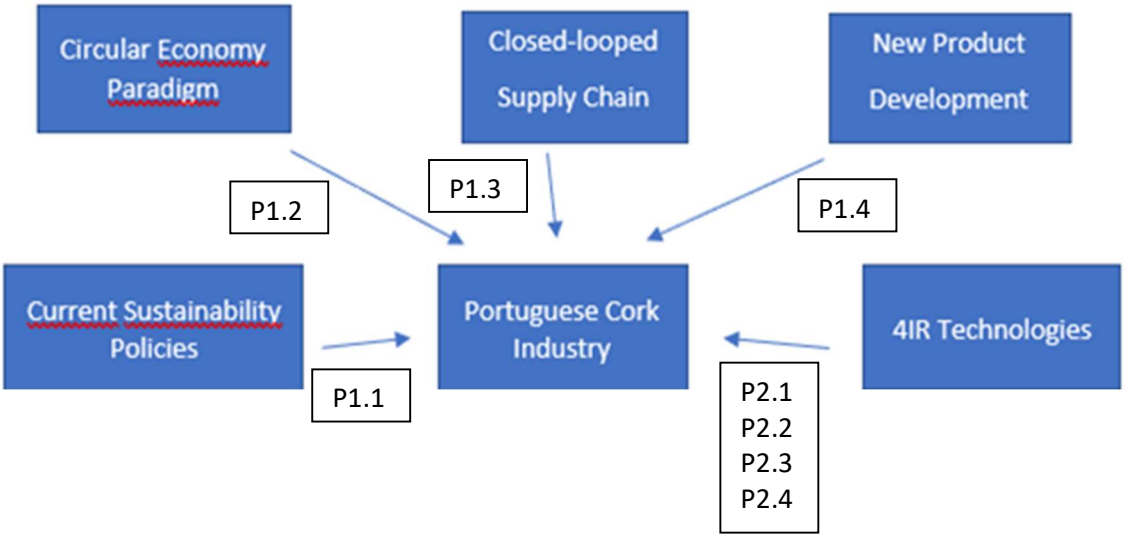

Figure 3.1. Research Framework

The illustration above (Figure 3.1.), was elaborated in order to obtain a simpler understanding on how each variable and each proposition are placed around the primary variable, the Portuguese cork industry.

4. Methodology

4.1 Research context - Portuguese cork industry

According to APCOR (2019), Portugal has the highest percentage of cork oak forest and is the number one competitor, with 34% and 49,6% of the world total, respectively. Furthermore, Portugal is the world leader in exports, reaching an impressive 62,4% of total exports, and the third-biggest importer, with almost 11%. This industry provides a career to, roughly, 9.000 people, divided into nearly 700 companies (APCOR, 2019). Nonetheless, it is estimated that more than 100.000 jobs are directly or indirectly related to cork (Mestre & Gil, 2011). As mentioned by Sierra-Pérez and his colleagues (2014), there are three primary stages in the cork sector's value chain:

1. The first one is managing the forest to extract the best cork quality and, thus, obtain better prices and higher margins. The outcome of this stage will have repercussions in the rest of the value chain.
2. The next step is denominated as "*the half-manufactured cork industry*", in which the raw-material will be transferred to a preparation factory, to be handled and then separated to each subsector of the industry.
3. The final stage is "*the cork-processing industry*" phase, where the resources are fully transformed and where the cork gains more value.

Geographically, the industry is distributed primarily in the Aveiro (north of Portugal) and Setúbal (south of Portugal) districts, with the first focused on the transformation process and the later specialized on the production and preparation stages. The fact that the industry has different stages of the supply chain almost 300 kilometers apart, has caused some northern companies to migrate south due to transportation costs (Mestre & Gil, 2011).

The cork products are originated from first quality cork (42% of all cork extracted), which is related to the cork stoppers, and second quality cork (58% of all cork extracted), mostly used for agglomerates (Ramos et al, 2019). In the Portuguese market, according to Mestre and Vogtlander (2012), the primary materials are natural cork, agglomerate composite, expanded cork and rubber cork.

In terms of sales, the industry divides itself into cork stoppers, with 71%, construction materials, reaching more than 25%, and the remaining percentages are related to other types of products, such as clothes (Mestre & Vogtlander, 2012).

The cork industry's dependency on cork stoppers is well recognised, particularly now with the wine sector estimated growth perspective. Until 2026, 3,25% is the expected growth value, which may increase the demand for cork stoppers from the wine industry. This connection to the wine sector may also enhance how dependent the Portuguese cork industry is to the environment (APCOR, 2019). Furthermore, only 2% of the total of cork stoppers sold on the national wine market were recycled, which does not help the industry to reduce the dependency on the environment (Green Cork, 2014).

Therefore, there are four main reasons why the Portuguese cork industry must start applying CE in its sector:

1. Dependency on raw material.
2. Climate changes.
3. The need for sustainable NPD in a C2C Industry paradigm.
4. Profitability.

Consequently, this thesis will seek to find solutions to these problems, create suggestions to solve them and, hopefully, help the Portuguese cork industry reinforce its prime position in the global cork sector.

4.2 Methodological general issues

To scientifically analyse and answer the scientific research questions, a qualitative approach is applied. A Multi-methodological approach is used to connect to existing research and to obtain new knowledge and research results specific to the sector. The first step is a theoretical literature analysis, followed by qualitative expert interviews to generate holistic insights about potential drivers, barriers, and motivation for the implementation of the CE principles in cork SME's. The research design and research process, as well as the specific reasons and scope of the research that fit to our objectives, were targeted to the research questions. Finally, the resulting findings are then used to fully enlighten the research question in the discussion chapter.

4.3 Research design

Having the premises and the object of the study defined, it is important to explain what the chosen methodological approach was. For this study, to better address the research problem, a dissertation and a qualitative methodological strategy were chosen, using the inductive method, which starts from the particular to the general.

The research must start with an analysis of the current state of the art regarding Cork business and Industry and then, correlate that with some key definitions to the project, such as LE, Sustainability and CE. The study in the Portuguese cork industry sustainability can only begin afterwards, to understand its current situation and deliver a superior critic. Thus, it is necessary to:

1. Define and analyse the current situation of the Portuguese cork industry when it comes to sustainability.
2. Know what the Portuguese cork industry can do to become more sustainable and embrace CE.
3. Understand how a different mentality in sustainable development affects the Portuguese cork industry.
4. Draw conclusions and elaborate an opinion on this issue.

For research development, qualitative, quantitative, or mixed data can be used. Qualitative data are mainly exploratory, allowing a deeper understanding of theory, opinions, or ideas. The methods used to obtain qualitative information can be through group discussions, individual or observation interviews, and the sample size is usually small and segmented. In the case of quantitative data, it is obtained through the generation of numerical data, and is subsequently converted into statistics that inform the trend of the study to be performed. To collect this data, it can be conducted by personal or online interviews, surveys on various platforms and through observation. Mixed data is a combination of these two sources of information.

This research had a qualitative methodological approach, through the compilation of information based on bibliographic reviews and an empirical study using a business semi-structured interview. Given this context, the preferable research design will be a qualitative research semi-structured interview directed to some players in this industry, such as Corticeira Amorim, and other stakeholders. Interviews are procedures where the researcher and the respondents are having a conversation regarding the phenomenon in question. The justification for conducting interviews is based on the ability to interact with the respondents and assemble in-depth answers. As the given research is about describing a phenomenon, interviews are in line with the criterion. semi-structured interviews are used for the given research. The choice of conducting semi-structured interviews is based on the ability to interact with the respondents and collect developed answers, since supplementary questions also are used, and still could compare the respondents' answers. As the given research is about describing a phenomenon, semi-structured interviews are in line with the criterion to get a deeper understanding around the chosen area.

Therefore, the approach will be used to gather information about goals and perspectives regarding sustainability and CE perceptions and perspectives. This thesis format will help to understand how sustainable the Portuguese cork industry is and what it is possible to change in order to improve its sustainability.

4.4 Data collection instrument and data analysis procedures

In this research, the secondary data was obtained through reviewing literature centred on the topics mentioned in this thesis, while the collection of primary data was performed through the use of interviews.

The current research is based on seven qualitative interviews with respondents with specialization and interest within cork industry, which were given the ability to generate a deeper understanding around the area of interest and provide various perspectives. Four scholars with interesting knowledge for this dissertation and three managers related to the Portuguese cork industry were interviewed, in an open manner, with the option to do the interview via an online meeting or via a written response. As mentioned before (chapter 1.5), the objective was to have at least ten interviews, however, these were the only people who gave a positive answer.

When conducting research, the selection of respondents is of importance, since the sample of respondents has a decisive matter on the results of the research. The collection of respondents for the given research is based on a non-probability sampling (Bryman & Bell, 2011). The respondents have been carefully selected based on each respondent's ability to generate valuable data for the research. The use of a non-probability sample is the most suitable for the study, since the data that is collected must fit the parameters of the study and fulfil the purpose.

Name	Age	Occupation
S.T.	40	Responsible for production in CPF – Cork, Lda
J.L.	54	General director of APCOR
E.P.	48	Professor at Instituto Politécnico de Viana do Castelo
J.M.	53	Professor at Evora University
N.A.	55	Professor at Evora University
R.F.	53	Professor at Evora University and director of CEFAGE
P.F.	61	CEO of Sofalca, Lda

Table 4.1. Interviewed Information

According to Bryman and Bell (2011) it is necessary to have a primary data collection tool. To create a tool that can be an interview script, it is necessary to create an operationalisation. This step offers the opportunity to translate theories into research aspects (Bryman & Bell, 2011;

Jacobsen, 2002). Concepts are several building blocks in a theoretical framework and play an essential role in research (Bryman & Bell, 2011). Concepts need to be concretised since they are often vague and complex (Jacobsen, 2002). The concepts examined in this study are taken from the theoretical framework (Chapter 3) and are listed below (Table 4.2). To check the concepts, several indicators are generated, which are presented in the interview questions.

Theoretical Concept	Concept Definition	Operational Definition	Questions
Circular Economy Paradigm	The concept of CE is related to the theories of sustainable and economic development and is characterized by reducing/eliminating waste from industrial activities and products used, by modifying the production processes and product design, encouraging maintenance, reuse and recycling	To describe how the respondents perceives the CE paradigm.	2a; 5; 6; 7.
Closed-Loop supply chain	Is a theory based on relating the end of a supply chain with is beginning, by collecting and processing used (or unused) products and provide it an economic, social and/or environmental value.	To describe how the respondents perceives the Closed-Loop supply chain and its importance.	4.
New product development	NPD is the process of designing and development new products based on market opportunities.	To describe how the respondents perceives the New Product Development in the Portuguese cork industry.	17; 18; 19.
Portuguese cork industry	The Portuguese cork industry is an industry centred on the development of cork oaks and the transformation of its outer bark (cork).	To describe how the respondents see the cork industry in Portugal.	3; 9; 12; 13; 16.
Sustainability policies in cork industry	Sustainability policies are guidelines related to the environment. In this case, these policies are originated from or created for the Portuguese cork industry.	To describe how the respondents perceives the sustainability policies' importance in the Portuguese cork industry.	1; 2b; 8.
I4.0 Technologies	Technologies related to the fourth industrial revolution. These technologies are known from its automation and big data exchange and analysis, with methods such as 3D printing, smart factories or the IoT.	To describe how the respondents perceives the I4.0 technologies importance in the Portuguese cork industry.	10; 11; 14; 15.

Table 4.2. Operationalisation Table

To refer that the interview script was designed addressing the theoretical framework accordingly to create research-relevant interview questions (Bryman & Bell, 2011). As a result, the questions asked during the interview were well designed to obtain valuable data. Interview questions are presented in an interview guide based on operationalising questions and reviewing concepts. Appendix 1 contains the interview guide.

Bryman and Bell (2011) point out how important it is to inform the respondent well about the research goal, the possibility of anonymous participation, and the research objectives before the interview starts. In the current study, the interviewer gave a complete presentation of oneself and a description of the research. In addition, the issue of anonymity was addressed, and it was pointed out that the data will only be used for the current research. The interview then began with the respondent talking about the concepts contained in the questions, explaining their perception so that the researchers could understand the respondent's point of view.

The interviews in the given study were conducted in Portuguese since it enabled a better interaction between the researcher and the respondent. Furthermore, the respondents were informed beforehand about the recording process and gave their consent.

Data Analysis Method

When collecting verbal data, such as in interviews commonly used in qualitative studies, the data is transferred into the text for analysis. In order to convert the primary data into text, the researcher rewrites the interviews' content to get an overview of the answers and to be able to compare the data of the empirical chapter with the theoretical reference. In addition, it is possible to find various touchpoints concerning the theoretical reference and the comparison with the primary data by looking for similarities and differences (Bryman & Bell, 2011).

The qualitative data analysis has three approaches into account, namely description, categorisation, and combination. The description concerns getting a clear picture of the data, as it is often very dense. Categorisation consists of reducing and systematising empirical material to get a better overview of information. Finally, the combination combines categories with theories to find the causes and meaning of the phenomenon under study (Jacobsen, 2002). In the current study, the collected, recorded material was first transcribed and compared with the notes made during the interview so that the researchers get a complete and more precise picture of what has been said. In addition, all notes and transcripts from each interview are compared to identify similarities or differences. According to Jacobsen (2002), citations in a qualitative study are essential to produce a more in-depth and more reliable study. In the current research, the quotes in the empirical chapter are used to increase the research's reliability and help the reader better understand what is being said in each interview. The descriptions that refer to different theoretical concepts based on the interviews will later be divided into different categories to facilitate data collection. Categories are used in the form of different concepts in the operationalisation to combine them and to be able to analyse

differences and similarities. This allows conclusions to be drawn about the insufficient knowledge on achieving wealth-generating sustainable products and services in the Portuguese cork industry in a CE framework.

Quality of Research

In research, it is essential to ensure the quality of the study. It can be done through evaluation of the research in comparison to the quality criteria, often referred to as validity and reliability. For the study to have a strong character and to be construed as trustworthy, the validity and reliability should be as strong as possible (Bryman & Bell, 2011). However, the authors explain that validity and reliability in qualitative research are presented as trustworthiness instead. It is also of significance to present the ethical and societal issues concerning the research, to make sure that the study is conducted in a fair way (Jacobsen, 2002).

Bryman and Bell (2011) define trustworthiness in four classes, namely credibility, transferability, dependability, and conformability. However, to address internal validity in a qualitative study, credibility instead of validity is the most often used concept since validity might be difficult to ensure, whereby credibility becomes more suitable. Credibility concerns the participants' point of views to fairly be represented in the study. Credibility is assured through a constant dialogue with the researchers about respondents' viewpoints on what is included in the study. The respondents have received the translated material which the researchers want to include, to make sure that the translations are representing the presented perspectives.

The second approach, transferability, regards the external validity of the study, in contrast to credibility, which parallels with the internal validity. It refers to if the results of the research can be transferred to other groups or contexts beyond the specific study (Bryman & Bell, 2011). In the given study, transferability can be assured, since it regards a sample of (scholars and managers related to) Portuguese natural product industry, which is able to endorse sustainable practices towards CE. So, the results may be transferred beyond the study's context if desired.

Dependability is the third approach and is often substituting reliability. Reliability can be problematic to establish since it focuses on the ability to repeat the study, and thus, dependability is preferred in qualitative studies. Instead of trying to ensure repeatability, the researcher should aim to provide a clear picture of the findings, so that any other researcher would end up with the same conclusions regarding the data. It is therefore crucial for the researcher to operate fairly and organized, so that the study becomes as comprehensive as possible (Bryman & Bell, 2011). Regarding the specific research, dependability is assured through systematic management and writing. Transcriptions during and after the interviews are

compared, to make sure that the data is precise. The operationalization also adds to the dependability, due to the possibility to see from which theory each question has derived, making it easier for others to understand what the empirical material has been based upon.

The last approach of trustworthiness is confirmability, which regards ensuring that the findings should not be influenced by the researcher's own personal values. However, true objectivity is impossible to assure, but it is important to try to avoid subjectivity (Bryman & Bell, 2011). Confirmability is established in the given study through the researcher being as objective as possible regarding the process and outcome, and are not affected by personal values, nor any preferred outcome.

The ethical considerations present in this research tackles four dimensions: (i) how the participants have been handled; (ii) the privacy concerns; (iii) if there is or can be a harm of the participants or a lack of information to the respondents regarding what the research is about, and (iv) whether or not deception is involved (Bryman & Bell, 2011).

Regarding societal considerations, the collected data regards the individuals' privacy thus, no personal information is a part of the specific study, except from the position each respondent holds.

5. Empirical Research - Interviews and results

In the following chapter, a collocation of the seven interviews is presented which is categorized on the basis of the conceptual framework (Figure 3.1).

The interviews conducted to four university professors, namely E.A., J.M., N.A. and R.F., all with knowledge related to the Portuguese cork industry, and to J.L. (APCOR's director), P.E. (CEO of Sofalca, Lda, specialized in black agglomerated products) and S.T. (Responsible for production in CPF – Cork, Lda, specialized in cork stoppers) allowed to dig deeper into the research questions and compare with the information obtained from the literature review, with hopes of getting some answers to those questions and reach a conclusion. The empirical data is presented and analysed in relation to the six theoretical concepts (Table 4.2).

Portuguese cork industry

These interviews also conclude that the current practices of this industry are adjusted to national and European directives and policies, due to the fact that Portugal is integrated in the EU, thus obligating its industries, including the cork sector, to develop their operations within the community rules. APCOR's director, J.L., commented this matter mentioning that "*We (the cork sector) believe that they are very beneficial goals and orientations*"[1]. These opinions confirm the harmony previously stated between EU and national policies and the Portuguese cork sector.

Circular Economy Paradigm

In terms of implementing a CE paradigm, the feedback was overall positive, with the interviewed mentioning that it could create new jobs, reduce costs and waste, create new products and new business models, thus, increasing the overall value of the industry. To introduce this paradigm, the investment in new technologies, as such originated from the 4IR, and processes in order to optimize activities and the investment in new products based on used cork are believed by all to be the most vital elements for the industry. Furthermore, it was mentioned that government support could be important and P.E. suggested that there should be an investment or an encouragement from the government to increase the number of cork oaks, as he stated "*It would be important that the government supported or increased the plantation of new trees*"[2], with the objective to increase the amount of raw material available. However, legislative changes and the creation of an Eco-Industrial Park had opposite opinions. The first was believed to be irrelevant by some and important by others, in order to create the

[1] In original: *Nós (sector da cortiça) entendemos que são metas e orientações muito benéficas.*
[2] In original: *Era importante que o estado apoiasse ou aumentasse a plantação de novas árvores.*

same rules and the latter due to being geographically impossible or irrelevant by some and something already happening by others. The collaboration of the industry stakeholders in order to implement CE policies it is essential and it is already happening.

Sustainability policies in cork industry

One of the most important information obtained from the interviews is related to sustainability and waste management, because everyone denied that 40% to 70% of waste was never used. All the answers indicated that the industry was very much sustainable, with few damaging processes for the environment and that it uses almost completely its waste, as mentioned by Prof. R.F. "*What I know about the cork industry is an industry relatively sustainable. It does not have very polluting processes and it does not have large waste. What it is not used on the more noble productions, such as stoppers production, it is then used to produced other products*"[3]and reenforced by Prof. N.A. which mentioned that "*I think that there is an attempt to use the product at its fullness, meaning that there is practically no waste, including the dusts are used for energy, which could be for the heating of the cooking waters or power generation*"[4]. Some of the interviewed admitted that there is room to improve and that the environmental policy is more focused on the "*No Waste Manufacturing*" paradigm than the CE paradigm. In order to improve, the interviewed suggested an investment in recycled products and further investigation and innovation in this area.

Closed-Loop supply chain

The interviews confirmed that it is difficult for the industry to return used cork stoppers in order to be utilised by the industry, as stated before (Chapter 4.1). It was mentioned that, in theory, it would be good for the industry to recycle the stoppers, given the necessity to increase raw material availability. Nonetheless, it is mandatory to conduct a study and understand if it would be economically and environmentally positive for the industry. It is believed that only national products cork could be returned, given the financial and environmental costs. This policy would only impact the non-cork stoppers products because recycled cork stoppers cannot be reused as cork stoppers, due to health standards.

[3] In original: *A indústria da cortiça naquilo que eu conheço é uma indústria relativamente sustentável. Não utiliza processos muito poluente e não tem grandes desperdícios. O que não é utilizado nas produções mais nobres, nomeadamente na produção de rolhas, depois é utilizado para produzir outro tipo de produtos*.

[4] In original: *Penso que há uma tentativa de utilizar o produto na sua completude, portanto não há desperdício praticamente nenhum, inclusivamente os pós são utilizados para energia, quer seja para energia de aquecimento das águas de cozedura das cortiças quer seja para geração de energia elétrica*

New product development

The interviewed stated that the industry has a lot of potential to develop new products and that innovation plays a critical role. Coincidently, the ability to create new products and maximize resource usage are seen as the main competitive advantage of the CE paradigm.

I4.0 Technologies

As stated in the literature review, it is critical for any industry to introduce new technologies to its operations, as it creates new business models and benefits the industry economically and socially. However, it was mentioned by the interviewed several problems to introduce these technologies, including some formerly declared, such as:

1. Difficulties in obtaining financial partners due to being a small industry.
2. No direct government support, and the existing tends to go for the bigger companies, due to being more capable of using the money, with some having their own R&D department. Nevertheless, APCOR tries to mitigate this issue by sharing knowledge to the smaller companies.
3. Too many bureaucracies.
4. Lack of technology availability and information.

Overall, the technology suggested to the interviewed had a positive feedback:

1. 3D printers: A technology owned by APCOR and that some companies use, would have no use in the stoppers sector.
2. Digital passports: Important to ensure maintenance and recycling, however it would have no use in the stoppers sector.
3. Traceability of products and ensuring sustainable origin and production: Already a reality and, according to J. Lima, the sector uses the Forest Certificate, which requires traceability
4. Digital waste management: Already a reality, according to J. Lima.
5. Augmented reality technology: Already a reality and, according to J. Lima, APCOR owns this type of technology.
6. Smart factories: Positive for the industry, however, P. Estrada mentioned that it would have no use in the black agglomerate sector.
7. Connecting companies in a network to share knowledge: Positive factor for the industry, as long as it does not take competitive advantage. However, it is something hard to implement due to one company controlling a large portion of the market.

Those opinions correlate with the literature review previously mentioned. However, adequate education was mentioned as a very important element to implement these types of technologies and J. Lima mentioned that APCOR has an education centre to help the companies.

5.1 ReSOLVE and EcoCanvas for the Portuguese cork industry

In order to evaluate the Portuguese cork industry with an international tool and facilitate its analysis to environmental matters, as well to some social and economic affairs, a ReSOLVE and an EcoCanvas (both mentioned in Chapter 2.2.3) were designed (Table 5.1 and 5.2, respectively).

ReSOLVE

Regenerate	• No cork waste in the production process. • Ashes originated from the production process is used to fertilize fields or forest. • Non-renewable energy if often change by cork waste.
Share	• APCOR shares knowledge and technology with all companies. • Companies with different needs and products interact often to provide cork waste not appropriate for one's business.
Optimise	• Maximization of raw material efficiency by using everything.
Loop	• Very efficient loop inside the industry. High levels of difficulty to return used products.
Virtualise	• Several processes automatize, such as waste management.
Exchange	• Raw material cannot be exchange for another one more environment friendly. • No need to upgrade its technologies, although the industry lacks 4IR technology. However, APCOR has and loans some of the 4IR technology, such as 3D printing and augmented reality.

Table 5.1. ReSOLVE analysis

EcoCanvas

Foresight & Impact (Environment)

- Climate change
- Wild fires

Impacts (Positive and Negative) generated by the industry:

- No waste
- Less use of non-renewable energy sources

Circular Value Chain

- Wine and construction costumers
- Suppliers and distributors
- Competitors
- Recycling sector

Problem/Challenge

- Minor recycling of used products
- Little raw material available

Key Resources

- Cork
- Equipment to cook cork

Circular Value Proposition

- Increase the Portuguese cork oak forest
- Increase the cork recycle campaigns and benefits for the participants

Product Description:

- Cork products

Stakeholders Relationships

- The companies depend on each other to used all cork available

Communication & Sales

- Social Media
- Local and international fairs
- Online and physical stores

Customer Segments

- Mainly wine consumers and construction companies, but an increasing number of other sectors has well
- Environmentally friendly costumers

Foresight & Impact (Social)

- Courses for the companies available through APCOR
- Growing trend towards a more sustainable business model
- Consumer's awareness on environmental issues increase

Impacts (Positive and Negative) generated by the industry:

- More jobs and jobs with higher education needed due to increase of technology level
- Increase social wellbeing due to environment improve

Structure Costs

General costs: Labour, rent and administration

Depreciation of machinery

Variable costs: Fuel, packaging, staff training

Revenue Streams

- Sales

Circular Business Model & Innovation

- Use of every waste created in the production process.

Table 5.2. EcoCanvas analysis

This analysis enable to analyse the Portuguese cork industry reality, summarizing its economic, social and, especially, environmental influences. By examining the previous ReSOLVE tool, the Portuguese cork industry has various forms of environmentally friendly policies, due to its "*Zero Waste Manufacturing*" paradigm. Furthermore, the interviewed believe that its industry already has the proper amount of technology, despite os studies showing how the 4IR technologies can benefit any industry. However, APCOR loans to it associates some 4IR technologies, such as 3D printing. In the EcoCanvas, the primary analysis are related to the industry environmental weaknesses, due to its high exposure to wildfires (common in Portugal) and to climate change. Furthermore, another weakness of the industry it's the high dependency on the wine sector. However, the tool also demonstrates the environmental and social benefits that this industry delivers.

6. Conclusion

After completing the Literature Review and the Empirical Research (Chapter 2 and 5, respectively), there are several final deductions that can be considered.

Nowadays, people tend to be more environmentally responsible and value companies with sustainable policies. Thus, since the CE model brings a lot more environmental improvements, by simply announcing the shift into a CE paradigm could be positive for an industry. However, the CE benefits goes beyond the environment, by generating several new jobs and allowing companies to reduce its costs, as shown in the study forecasting that a CE paradigm in the EU would create new jobs and to reduce costs by 600 billion dollars, with a proper management of resources and waste. Therefore, being the Portuguese cork industry in the EU zone, it may be assumed that a CE paradigm would also have a positive impact in the industry. However, although the Portuguese cork industry sustainable practices are in syntony with the EU and Portuguese policies, the focus is on a "*No Waste Manufacturing*" model for three primary reasons.

The first and most important concern in the Portuguese cork industry is the lack of available material. Although the increasing of cork oaks trees is encouraged by the industry, this will be prolonged process due to the slow growing characteristics of the Cork Oak tree and the extensive time needed for the outer back be ready for a high quality product, leading to recycling and reusing as the main solution for a short/medium-term. However, the industry has modest capability to recycle used products, especially cork stoppers, which that qualifies for 70% of sales, as demonstrated by the Green Cork, Corticeira Amorim and Sonae initiative that only manage to recycle 2% of cork stoppers in the national market, in 2014. However, this stoppers cannot be used to produce more stoppers due to health regulations, meaning that secondary products in the industry would benefit the most with this type of program. Thus, in theory, the Portuguese cork industry would profit if it could close the loop of its supply chain and manage an efficient recycling process. However, since this information was not available, it is impossible to determine if the recycling benefits would be higher than the logistical costs of returning the products to factories.

Another obstacle is related to how the industry uses cork. Cork is a natural material with a rising appreciation of its characteristics. Once seen as a resource merely suitable for stoppers, the cork industry now has costumers in many different areas and started to emerge in automobiles, spaceships, fashion, among others. Cork is a versatile material and the emergence of new technologies and methods enables companies to use cork in different ways. However,

regardless of the R&D budget available and the rising number of patents, which most of them are never tested in market, due to only a hand full of firms having the finance capability to actually launch new products, the industry remains too focus on cork stoppers.

Finally, the third point is related to the technology applied in the industry, which is a key factor for a proper CE implementation, as previously mentioned (Chapter 2.2.5). In the Portuguese cork industry, although the technology requirements are fulfilled for the proper function of the industry, the implementation of the I4.0 technology would be valuable. APCOR already has some of these technologies, such as 3D printer and augmented reality, which are available to its associates and are primarily destined by non-cork stoppers companies. Another tool valuable would be the digital passport, but, once again, not for cork stoppers. However, in this final argument, the greatest concern is the lack of funds that could assist the Portuguese cork industry to implement these technologies and this happens especially because of the difficulty of the Portuguese cork industry to arrange partnerships with big international players due to being relatively small industry.

Regardless of these three challenges, the benefits of a CE paradigm are well demonstrated in this thesis. If the model could be implemented properly, the raw material available would increase and the secondary products could grow due to the rise resource availability, that are not destined to cork stoppers, and due to the I4.0 technology that would mainly benefit those products. Furthermore, with the diversification of its portfolio and the rise of other Portuguese cork industry segments, it could become easier for the industry to obtain the partnerships it needs to fully modernize.

The following table is meant to check if the research propositions were verified or not, in order to summarize the investigation.

Proposition	Verification	Remarks
P1.1: The sustainability policies in the Portuguese cork industry are already fully related to the Circular Economy paradigm.	Partially verified	The Portuguese cork industry policies are oriented towards a "*No Waste Manufacturing*" paradigm, which has similar notions, but it covers an inferior portion "*cradle-to-cradle*" process.
P1.2: The Portuguese cork industry benefits from a Circular Economy paradigm.	Verified	Verified through literature review and interviews.
P1.3: The Portuguese cork industry benefits from a closed-looped value chain and from reusing and recycling materials and	Partially verified	In theory, the Portuguese cork industry could benefit from reusing and recycling materials due to its ability to use every

		cork particle. However, since there would be cost related to the logistics that could not be calculated, it cannot be stated with certain that there would be profit.
P1.4: The Portuguese cork industry benefits from new product development.	Verified	Verified through literature review and interviews.
P2.1: The Portuguese cork industry uses I4.0 technologies.	Verified	Verified in the interviews.
P2.2: The I4.0 Technologies are drivers for Sustainability and Circular Economy practices in the Portuguese cork sector.	Verified	Verified through literature review and interviews.
P2.3: The drivers and hampers to introduce I4.0 technologies in the Portuguese cork industry are political, social and/or economic.	Verified	Verified in the interviews.
P2.4: A change towards a Circular Economy paradigm, using I4.0 technologies, benefits the Portuguese cork industry.	Verified	Verified through literature review and interviews.

Table 6.1. Research propositions verification

By analysing the previous table (Table 6.1), we may conclude that only P1.1 and P1.3 were partially verified and that the rest of the prepositions were all verified.

7. Limitations and suggestions for future investigation

Although the main objectives were achieved, this research had several obstacles to overcome. The reduced number of interviews that I was able to arrange and the lack of investigation regarding the Portuguese cork industry, especially when it comes to relating it to the CE and 4IR, were the primary problems for the outcome of this study.

In terms of future investigation, I would consider: (i) the study of the NPD capacity in the Portuguese cork industry and how and if it can outperform cork stopper sector; and (ii) a deeper study in how the 4IR technologies would influence the Portuguese cork industry.

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