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Environmental and Social Impacts of Cork Products and Forest Bioenergy

Corticeira Amorim and Omnipellets Case Study

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Declaração

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

Declaration

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

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Resumo

O conceito de sustentabilidade apareceu pela primeira vez em 1713 na Saxónia, Alemanha. A cidade estava a passar por uma crise de escassez de madeira e o conceito surgiu como uma maneira de combater esta crise. Desde então, o conceito evoluiu e, atualmente, a sustentabilidade baseia-se em três pilares: económico, ambiental e social.

As florestas detêm um papel fundamental no ambiente, na população mundial e na economia global e têm também o potencial de promover o desenvolvimento sustentável. As ameaças que estas enfrentam fazem com que as florestas sejam ainda mais relevantes na realidade atual. Em Portugal, o setor florestal tem um papel particularmente importante.

Este estudo tem como objetivo avaliar os pilares ambiental e social, aplicados a produtos florestais de empresas portuguesas (rolhas de cortiça naturais e pellets), através das metodologias Análise Ambiental de Ciclo de Vida (A-ACV) e Análise Social de Ciclo de Vida (S-ACV). A A-ACV e a S-ACV são técnicas que servem para avaliar, respetivamente, os impactos ambientais e sociais de todas as etapas do ciclo de vida de um produto/serviço/processo.

De acordo com os resultados obtidos, o ciclo de vida das rolhas tem menos impactos ambientais e sociais do que o dos pellets. As questões ambientais mais críticas no setor florestal são a ecotoxicidade marinha e terrestre e a toxicidade carcinogénica humana. As questões sociais mais críticas neste setor são as lesões e fatalidades, os riscos e acidentes no trabalho e a corrupção.

Palavras-chave: Análise Ambiental de Ciclo de Vida; Análise Social de Ciclo de Vida; Cortiça; Bioenergia Florestal

Abstract

The sustainability concept first appeared in 1713, in Saxony, Germany. The city was living a crisis of timber scarcity and the concept arisen as a way to fight this crisis. Since then, the concept has evolved and nowadays, sustainability relies on three different pillars: economic, environmental, and social. The first one is the oldest one (and also the most studied), followed by the environmental one and then, the social field is the most recent and least studied one.

Forests have the potential to help and promote sustainable development. They have a vital role in the global environment, population, and economy. Their relevance in today's World is huge and increasingly important because of the threats they face. Particularly in Portugal, forests have a fundamental role.

Thus, the present study aims to assess the two least studied pillars of sustainability (environmental and social), applied to forest-based products from Portuguese companies (natural cork stoppers (NCS) and pellets) using the Environmental and Social Life Cycle Assessment methodologies (E-LCA and S-LCA). E-LCA and S-LCA are techniques that can be used to evaluate, respectively, the environmental and social impacts of a product's life cycle.

According to the results obtained, the life cycle of NCS has fewer environmental and social impacts than the pellets life cycle. The most critical environmental issues for the forest sector are marine and terrestrial ecotoxicity, and human carcinogenic toxicity. The most critical social issues for this sector are the Injuries & Fatalities, the Occupational Toxics & Hazards, and the Corruption.

Keywords: Environmental Life Cycle Assessment; Social Life Cycle Assessment; Cork; Forest bioenergy

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List of Abbreviations and Acronyms

AA - Aquatic Acidification

A-ACV - *Análise Ambiental de Ciclo de Vida*

ADW - Access to Drinking Water

AE - Aquatic Eutrophication

AEco - Aquatic Ecotoxicity

AHB - Access to Hospital Beds

APCOR - *Associação Portuguesa da Cortiça*

AS - Access to Sanitation

BU – Business Unit

C – Carcinogens

CC - Climate Change

CD - Communicable Diseases

CL - Child Labour

Cm – Community

Cr - Corruption

CS – Case Study

CoS - Children out of School

D – Discrimination

ECO - Ecosystems

E-LCA – Environmental Life Cycle Assessment

EQ - Ecosystems Quality

EWT - Excessive Working Time

FE - Freshwater Eutrophication

FEco - Freshwater Ecotoxicity

FL - Forced Labour

FoA - Freedom of Association, Collective Bargaining, and Right to Strike

FPMF - Fine Particulate Matter Formation

FRS - Fossil Resources Scarcity

FU – Functional Unit

G - Governance

GDP – Gross Domestic Product

GE - Gender Equity

GHG - Greenhouse Gas

GVA – Gross Value Added

GW - Global Warming (ReCiPe)

GW2 - Global Warming (IMPACT 2002+)

HCT - Human Carcinogenic Toxicity

HCZ - High Conflict Zones

HH - Human Health (ReCiPe)

HH2 - Human Health (IMPACT 2002+)

HNCT - Human Non-carcinogenic Toxicity

HR - Human Rights

HS - Health & Safety

IF - Injuries & Fatalities

IR - Ionizing Radiation (ReCiPe)

IR2 - Ionizing Radiation (IMPACT 2002+)

IRi - Indigenous Rights

ISO - International Organization for Standardization

LC – Life Cycle

LCC - Life Cycle Costing

LCI – Life Cycle Inventory

LCIA – Life Cycle Impact Assessment

LDPE - Low-density Polyethylene

LHS - Latin Hypercube Sampling

LLC - Labour Laws & Conventions

LO - Land Occupation

LRDW - Labour Rights & Decent Work

LS - Legal System

LU - Land Use

ME - Marine Eutrophication (ReCiPe)

ME2 - Mineral Extraction (IMPACT 2002+)

MEco - Marine Ecotoxicity

ML - Migrant Labour

MRS - Mineral Resources Scarcity

NC - Non-carcinogens

NCS – Natural Cork Stoppers

NCD - Non-Communicable Diseases and other health risks

NRE - Non-Renewable Energy

OF - Ozone Formation

OLD - Ozone Layer Depletion

OTH - Occupational Toxics & Hazards

P – Poverty

PSILCA - Product Social Impact Life Cycle Assessment

R - Resources (ReCiPe)

R2 - Resources (IMPACT 2002+)

RI - Respiratory Inorganics

RO - Respiratory Organics

ROW – Rest of the World

S-ACV - *Análise Social de Ciclo de Vida*

SB - Social Benefits

SCF - Smallholder vs. Commercial Farms

SGD – Sustainable Development Goals

SHDB – Social Hotspots Database

S-LCA – Social Life Cycle Assessment

SOD - Stratospheric Ozone Depletion

SS – Single Score

TA - Terrestrial Acidification (ReCiPe)

TA2 - Terrestrial Acidification (IMPACT 2002+)

TEco - Terrestrial Ecotoxicity (ReCiPe)

TEco2 - Terrestrial Ecotoxicity (IMPACT 2002+)

U - Unemployment

UK – United Kingdom

UN – United Nations

UNESCO - United Nations Educational, Scientific and Cultural Organization

USD – United States Dollar

W - Wage

WC - Water Consumption

WWF - World Wild Fund for Nature

1. Introduction

This chapter presents, firstly, the problem's contextualization in Section 1.1. Next, the dissertation's objectives are displayed in Section 1.2. To finalize this chapter – in Section 1.3 - a brief description of the dissertation's six chapters is presented (dissertation's structure).

1.1 Problem Contextualization

The first appearance of sustainability concept dates the year of 1713. The city of Saxony, in Germany, was having a crisis of timber scarcity. The livelihood of a large part of this population was dependent on the mining industry, and this industry was consuming whole forests. Trees had been cut and not replaced for decades, which culminated in this scarcity timber crisis. In this sequence, the idea of sustainability was first introduced by Hans Carl von Carlowitz, a German tax accountant and mining administrator, in his book *Sylvicultura oeconomica* (von Carlowitz, 1713). Since then, the concept of sustainability has evolved and has been a matter of study. Sustainable development can be defined as the "*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*." (World Commission on Environment and Development, 1987). This sustainability definition given by the World Commission on Environment and Development is from the year 1987, more than 200 years after the first appearance of this concept. Therefore, the sustainability concept has been the subject of study and evolved in that period of time.

This issue is of such importance that even organizations like the United Nations (UN) debate daily about sustainability and work to solve problems related to this matter. In 2015, the UN set a group of 17 global goals, sustainable development goals (SDGs), to improve the planet and the lives of its citizens by 2030. These goals are not to be achieved at one moment in time and then to be forgotten, as Silva & Figueiredo (2020) say: "*SDGs must be continuously achieved in different places and recurrently in time to reach the definition of sustainability*".

Sustainability relies on three different pillars: economic, environmental, and social. The first one is the most measurable and objective one. There are several indicators to measure the performance of a company in the economic field. The other two dimensions are harder to quantify because they have a higher degree of subjectivity. However, the three dimensions are equally important. Santos, Carvalho, Barbosa-Póvoa, Marques, & Amorim (2019) elaborated an article that reviews 188 papers and in that universe of articles it was possible to conclude that: "*Most of the studies reviewed (84.6%) considered only two sustainability dimensions: economic (31.9%), environmental (13.8%), or a combination of both (38.8%). The first study including the three sustainability dimensions was published in 2005.*". Therefore, this shows that the economic pillar is the most explored one, following the environmental and lastly the social pillar. So, it is important to elaborate more studies and increase knowledge about the least studies ones, since as previously referred, they all have the same level of importance.

Forests have a vital role in the global environment, population, and economy. Their importance relies on fundamental issues such as providing food, renewable raw materials, jobs and incomes for millions of people, as well as relieving the effects of climate change by capturing and storing carbon. They are also the habitat for innumerable species, and they are an extremely rich biological area. "*Forests are among the most biodiverse ecosystems on the planet and are home to about 80 percent of the world's land-based animals and plants*" (PEFC, 2019d)[1]. Another benefit of the forest is related to water – a vital good – and is the fact that about one-third of the world's biggest cities get a significant part of their drinking water from forest areas; also 75% of the world's freshwater (for domestic, agriculture, industrial and ecological needs) comes from forested watersheds (PEFC, 2019a). Last but not least, the indigenous people have their homes located in forest areas as well as their local communities, livelihood and local employment (PEFC, 2019a).

The forests are directly related to sustainability and they have the potential to help and promote sustainable development. A good example of the influence that forests can have in global sustainability is their correlation to the SDGs (PEFC, 2019b):

- SDG 1 (No poverty – End poverty in all its forms, everywhere): Forests generate several jobs during all value chain of forest-based products and contribute to economic growth;
- SDG 2 (No hunger – End hunger, achieve food security and improved nutrition and promote sustainable agriculture): Forest provides several fruits such as mushrooms, nuts, berries, etc.;
- SDG 7 (Affordable and clean energy – Ensure access to affordable, reliable, sustainable and modern energy for all): Nowadays, energy from wood provides around 40% of global renewable energy;
- SDG 15 (Life on land – Protect, restore and promote sustainable use of terrestrial ecosystems, **sustainably manage forests**, combat desertification, and halt and reverse land degradation and halt biodiversity loss): This goals talks specifically about sustainable management of forests and the importance of life on land;
- These are just some examples that reinforce the importance that forests have in our World and their direct impact on the sustainability measures.

It is important to point out that with all these benefits that forests have, which are rather essential to the general population's well-being, they are a relevant topic in today's World, especially because of all the threats and challenges that they face in nowadays' reality.

The Portuguese forest occupies 3.2 million hectares which correspond to 35,4% of the Portuguese land. Portugal's economy strongly relies on forest activities and they have a strong

[1] The Programme for the Endorsement of Forest Certification (PEFC) is a global alliance of national forest certification systems, where Portugal is also included. It is a non-profit and non-governmental international organization that is dedicated to promoting **sustainable** forest management through independent third-party certification (PEFC, 2019c).

impact on the Portuguese GDP (gross domestic product) – around 4,7% of the national GDP. Forest-based products (such as paper, board, pulp, cork, wood, resin products, and furniture) represent 10% of the total national exportations and 3% of GVA (gross value added) (PEFC Portugal, 2017). In terms of social benefits, the Portuguese forest also plays a fundamental role when it comes to providing livelihoods. This economic sector generates about 113 thousand direct jobs (around 2% of the active population) (PEFC Portugal, 2017). Since the forest has such a highlight position in the national economy, during the 20th century, there were several ongoing initiatives aiming to promote the forestry in a big scale – in this period of time, the Portuguese forests increased their area from 2 million to 3.2 million hectares (an increase of 60%). There is an incentive in Portugal to promote forest activity and its maintenance in a sustainable way, taking into account the social, economic and environmental impacts (PEFC Portugal, 2017). The combination of all these factors and numbers (impact that the forest sector has in the Portuguese GDP – 4,7% –, the area that the forests represent in Portugal – 35,4% –, the number of jobs this sector generates – 113 thousand direct jobs –, etc.) explains why the forest sector is relevant in Portugal and should be the object of study.

In order to summarize the main ideas of this section, the target of this dissertation is to perform the assessment of two pillars of **sustainability**, **environmental and social**, applied to **forest-based products** from **Portuguese** companies through **E-LCA** (Environmental Life Cycle Assessment) and **S-LCA** (Social Life Cycle Assessment) methodologies. E-LCA and S-LCA are techniques to evaluate, respectively, environmental, and social impacts throughout all stages of the life cycle (LC) of a product/service/process.

1.2 Dissertation's Objectives

This dissertation's objectives are:

- To contextualize the problem under study;
- To explore the history of sustainability;
- To elaborate a state-of-the-art about E-LCA and S-LCA and their application to cork and forest bioenergy industries, in order to obtain a comprehensive knowledge of the software, methods, boundaries and categories commonly used in the implementation of these methodologies;
- To introduce the research methodology used during the development of the present work, including the E-LCA and S-LCA methodologies;
- To present an overview of Corticeira Amorim and Omnipellets companies (which are the two case studies);
- To apply the E-LCA methodology to both case studies (CS);
- To apply the S-LCA methodology to the CSs;

- To formulate conclusions regarding the methodologies application to the CSs and to reflect about the future work that ca be done.

1.3 Dissertation's Structure

The present dissertation is composed by six chapters:

- **Chapter 1 – Introduction**: In the present chapter, the subject of this project is described and contextualized, given into account the forest sector situation in Portugal. The dissertation project's objectives are also presented in Chapter 1, and lastly the document structure is described;
- **Chapter 2 – Sustainability**: The second chapter takes an overview to the sustainability concept and its history. The history of the three pillars of sustainability – economic, environmental, and social – is also explored.
- **Chapter 3 – State-of-the-art**: This chapter aims to clarify the concepts and methodologies (E-LCA and S-LCA) that are needed throughout the dissertation. After the concepts' definition, it is performed a research of the articles which apply E-LCA and S-LCA methodologies to cork and forest bioenergy products. The chapter ends with a conclusion that gives an overview of what was done over the years in this field of study and reflects about what are the most common approaches;
- **Chapter 4 – Research Methodology**: Chapter 4 illustrates the four steps that make up the research methodology. The four steps are: Step 1 – Case studies contextualization; Step 2 – E-LCA application; Step 3 – S-LCA application; and lastly, Step 4 – Comparison of systems. These four steps are explained in detail.
- **Chapter 5 – Results**: This chapter is subdivided into three main sections: 5.1) Corticeira Amorim, 5.2) Omnipellets and 5.3) Comparison of systems. The first two sections follow the same structure: first, Step 1 of the research methodology is applied (the case studies contextualization, which include the companies' mission and vision and business units); then, Steps 2 and 3 (E-LCA and S-LCA) are applied to the products under study (natural cork stoppers and pellets). The last section of this chapter, Section 5.3, is the application of Step 4 of the methodology – the comparison of systems. This last section gathers the results obtained from the application of both methodologies (E-LCA and S-LCA) to the two products and draws conclusions.
- **Chapter 6 – Conclusions and Future Work**: The last chapter takes an overview to the dissertation, looking to its limitations and conclusions taken along the way. The aim of this chapter is to reflect about the future work that can be done aligned with the present thesis, and also to elaborate conclusions about the overall work performed here.

2. Sustainability

This chapter aims to give a background about the sustainability concept. The chapter starts by illustrating the history of the sustainability concept (Section 2.1). Then, the focus moves to the three sustainability pillars: economic, environmental, and social. Each of these pillars has a subsection for them (Subsections 2.1.1, 2.1.2 and 2.1.3, respectively). The last section is the chapter conclusion (Section 2.2).

2.1 Sustainability history

As said in the beginning of Chapter 1 (in Section 1.1), the first appearance of sustainability concept was in the year of 1713 (von Carlowitz, 1713). Since that moment on, the concepts of sustainable development and sustainability have been progressing and studied for numerous entities. Figure 1 shows the history of sustainability: the chronological evolution of the concept since its very beginning in 1713 and its major milestones. Bellow, a detail explanation of these milestones takes place.

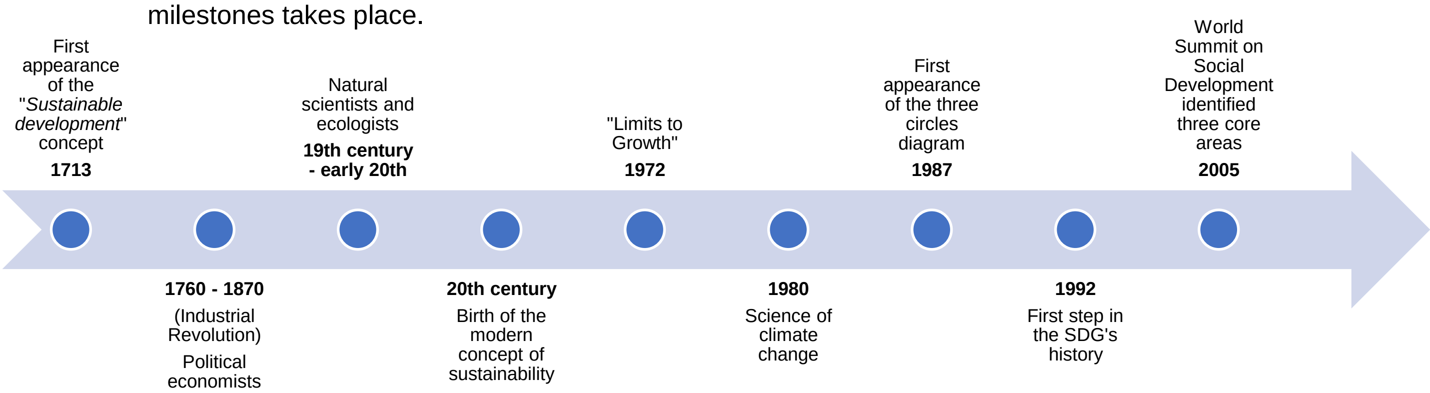

Figure 1 - Timeline of the sustainability concept

1713 So, as mentioned, in 1713 was the first appearance of the sustainable development concept by Hans Carl von Carlowitz, in his book *Sylvicultura oeconomica* (von Carlowitz, 1713).

1760-1870 Then, during the Industrial Revolution (between the years of 1760 and 1870), the political economists questioned the limits of economic and demographic growth, and with that, they recognized the trade-offs between wealth generation and social justice. With their reflections about the topic, they ended up thinking about sustainability and gave an important contribution to this subject (Purvis, Mao, & Robinson, 2019).

19th century – early 20th The next mark in the history of sustainability is the 19th century and the early 20th. The natural scientists and ecologists gave their input to the topic, when exploring the differences between the anthropocentric conservationists and the biocentric preservationists. The anthropocentric conservationists defended that the reason behind the conservation of the natural resources was the sustainable consumption. On the other hand, the biocentric preservationists supported that the nature preservation should be done because of its inherent worth (Purvis et al., 2019). So, the natural scientists and ecologists were, in fact, thinking about the reasons behind sustainable development.

20th century Even though some Renaissance and Enlightenment philosophers had expressed their concerns regarding the natural resources and the over-population (and if that would be sustainable in long term), they were not taken seriously at the time, and their studies were considered as just hypothetical questions (Environmental Science, 2020). It took until the 20th century for people to accept and understand the impact that humankind could have in the environment. Problems such as environmental damage, pollution, destabilising soils by cutting down trees, fossil fuels and other environmental issues led to a growing concern about the environment and that rose questions such as whether we were (or could) be damaging our own ecosystem (Environmental Science, 2020). Therefore, that was the kind of mentality that started the modern concept of sustainability and triggered all the investigations and studies around the topic (Purvis et al., 2019). Also during the 20th century, after the World War II, the United Nations (UN) was founded in October 1945 (United Nations, 2020b). Shortly after, in November of the same year, UNESCO (United Nations Educational, Scientific and Cultural Organization) was also established. These two organizations had and have a key role when it comes to sustainability issues worldwide. Nowadays, the UNESCO mission is "*to contribute to the building of peace, the eradication of poverty, **sustainable development** and intercultural dialogue through education, the sciences, culture, communication and information*" (UNESCO, 2017). Besides that, later on, the UN also built seventeen Sustainable Development Goals (SDGs). The history of the SDGs will be explained later on since their first developments only started in 1992 (late 20th century) (United Nations, 2020a).

1972 Another important landmark in sustainability's history was in 1972, when the book "Limits to Growth" was released (Meadows, Meadows, Randers, & Behrens III, 1972). This books marks the first modern appearance of the sustainability term in a broad and global context (Purvis et al., 2019). The book argues for a World system that is sustainable. Meadows et al. (1972) studied the exponential economic and population growth with a finite supply of resources, using a computer simulation. The model developed by the authors was based on five variables: population, food production, industrialization, pollution, and consumption of non-renewable natural resources. At the time, the variables were increasing and it was assumed that they would continue to grow exponentially. Meadows et al. (1972) explored the possibility of a sustainable solution that could be achieved by altering the growth trends among the five variables. After the publication of the "*Limits to Growth*" (Meadows et al., 1972), the sustainability concept snowballed and several studies and books followed, talking about the theme.

1980 By the end of the century, the science of climate change was firmly established (Environmental Science, 2020). In the 1980s, the problems of the greenhouse effect were known and clear, as well as the complications related to the destruction of the ozone layer. Also, around those years, the notion that the natural resources (in particular the fossil fuels) were finite became factual. With that reality, a lot of initiatives targeting the alteration of the energy source to renewable ones started showing up and becoming popular. Those events marked the social, economic and scientific birth of the environmental movement (Environmental Science, 2020).

1987 There is not a specific point of origin for the three pillar conception (economic, environmental, and social), yet it was a gradual emerge of the concept. But even with this progressive development of the three pillar view, there was a remarking moment in their history: the first appearance of the three circles diagram in 1987 by Barbier (Barbier, 1987). Also in 1987, The Brundtland Commission described sustainable development as the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commission on Environment and Development, 1987). That statement appeared in a report by the World Commission on Environment and Development entitled "*Our Common Future*".

1992 The history of the Sustainable Development Goals (SDG) was built during decades of work by countries together with the UN (including the UN Department of Economic and Social Affairs). Nevertheless, the SDGs very beginning was in 1992 when at the Earth Summit in Rio de Janeiro, Brazil, more than 178 countries adopted Agenda 21 (which is a comprehensive plan of action to build a global partnership for sustainable development to improve human lives and protect the environment (United Nations, 2020a)). In September 2000, the Member States adopted the Millennium Declaration (that featured eight Millennium Development Goals (MDGs) which aimed to reduce extreme poverty by 2015). In 2012, at the United Nations Conference on Sustainable Development (Rio+20), the Members States decided to develop the SDGs based on the MDGs already established. In the next year, the General Assembly set a 30-member Open Working Group to create a proposal on the SDGs. The General Assembly decided, in 2015, about the adoption of the 2030 Agenda for Sustainable Development that contained, inter alia, the 17 SDGs as its core. In 2015 as well, several other landmarks took place, such as the Sendai Framework for Disaster Risk Reduction, the Addis Ababa Action Agenda on Financing for Development, and the Paris Agreement on Climate Change; all of these are agreements that, among other things, promote sustainability (United Nations, 2020a). The seventeen SDG are (United Nations, 2020a):

1 – No poverty	7 – Affordable and clean energy	13 – Climate action
2 – Zero hunger	8 – Decent work and economic growth	14 – Life below water
3 – Good health and well-being	9 – Industry, innovation and infrastructure	15 – Life on land
4 – Quality education	10 – Reduced inequalities	16 – Peace, justice and strong institutions
5 – Gender equality	11 – Sustainable cities and communities	17 – Partnership for the goals
6 – Clean water and sanitation	12 – Responsible consumption and production	

2000 Another relevant landmark was in 2000 when Switzerland became the first country to add the term "*sustainable development*" to its constitution. One can read in Article 2 (since January 1, 2000): "*The Swiss Confederation supports the common welfare, the **sustainable development**, the internal cohesion and the cultural diversity of the country*" (Spindler, 2013).

2005 In 2005, the World Summit on Social Development officially identified three core areas that contribute to the philosophy and social science of sustainable development; these three areas are: economic development, social development and environmental protection (Environmental

Science, 2020). According to many national standards and certification schemes, these three pillars represent the core areas/issues that today's World faces. Also in 2005, the report by the World Commission on Environment and Development entitled "*Our Common Future*" (World Commission on Environment and Development, 1987) reflects about the process of decision making and that we must consider the future (and the future consequences) when making our own decisions about the present.

21st century Nowadays, sustainability has become a big topic which is transversal to several areas. As Spindler (2013) says, the 21st century has been chosen as the "*century of sustainable development*". Reidel (2010) also reinforces that idea by commenting that: "*The term 'sustainable development' seems to be enjoying immense popularity. No speech about the future of our society is complete without it, it serves as a slogan used by politicians, regularly keeps lawyers occupied, is a hot topic among scientists and increasingly discussed by the board of directors of corporations*" (Reidel, 2010, p. 96).

Apart from the obvious popularity of the term, the UN keeps actively working in their SDGs and they have today a Division for Sustainable Development Goals (DSDG) inside the Department of Economic and Social Affairs (UNDESA). The Division provides support to the SDGs and to related issues such as water, energy, climate, oceans, urbanization, transport, science and technology (United Nations, 2020a). The UN are committed to fulfil their goals.

As previously mentioned, the scientific community now agrees on the three pillar division: economic, environmental, and social. Although they might appear with different denominations such as pillars, dimensions, components, stool legs, aspects, perspectives, etc. (Purvis et al., 2019); the environmental pillar can also show up under the name ecological; and the economic pillar as governance pillar. The next subsections, 2.1.1 to 2.1.3, cover these three pillars: economic, environmental, and social one, respectively.

2.1.1 Economic pillar

The economic pillar is the oldest of the three. As Beattie (2019) says, this pillar is the one where most businesses feel more comfortable with. A business, in order to be sustainable, needs to be profitable; that is common sense and a transversal fact to all business areas. However, profit cannot outdo the other pillars and the values of the company. This means that trying to achieve profit at all costs is not what the economic pillar stands for (neither the sustainability ideology). This dimension of sustainability encompasses certain activities that are aligned with its values: such as compliance, proper governance, and risk management (Beattie, 2019).

The economic pillar is also known as governance pillar, which stands for the harmonization of all stakeholders' interests – board of directors, workers, shareholders, surrounding community, value chain intervening, customers, etc. (Beattie, 2019). This means that this sustainability dimension is in charge of avoiding the conflicts of interests among the interested parts. Furthermore, this pillar comprises other activities that include: assuring that the company do not use any political contributions to obtain unduly favourable treatment; ensuring that the accounting methods are accurate and transparent; making sure that the stockholders are given an opportunity to vote on important issues; assuring that the company do not engage in illegal practices; these are some examples of the scope of the governance pillar – and that name comes exactly from here, since the key idea it to ensure good governance policies.

In terms of metrics, there is has a quantitative method that analyses the economic impacts throughout the life cycle of the system under study. The method in question is the Life Cycle Costing (LCC) and it was created in 1965 in the report "*Life Cycle Costing in Equipment Procurement*", published by the United Stated Logistics Management Institute. Then, in 1974, the life cycle costing concept was accepted by the United States Department of Health, Education, and Welfare in Florida (Petrillo, De Felice, Jannelli, & Minutillo, 2017). This method can be defined as "*the total cost for all activities involved in product manufacturing from the development process to manufacturing stage, and usage stage until disposal stage*" (Jiran, Mahmood, Saman, & Yusof, 2013). LCC is standardized for the building and construction sector, by the ISO 15686-5, first developed in 2008 (ISO, 2017). The aim of the Life Cycle Costing approach is to determine the lowest possible cost of a product during the course of its entire life cycle (Jiran et al., 2013). However, this methodology is not widely used because it lacks in terms of formal guidelines and standardized information when it comes to other industries rather than building and construction (Jiran et al., 2013).

2.1.2 Environmental pillar

The second pillar is the environmental one – and to many, the primary concern of the future of humanity (Environmental Science, 2020). The environmental pillar stands for the environmental protection. The idea of a sustainable future passes, of course, for a sustainable (and existing) planet; so, in order to maintain the planet Earth, the notion behind this pillar is to protect and damage the least possible the environment. There are already several companies that focus on the environmental dimension – companies that are adopting measures such as reducing their carbon footprints, packaging waste, water usage, etc. Besides the ethical side of not being harmful to the planet, a lot of companies also found that having a beneficial impact on the planet can actually have a positive financial impact (like for example reducing the amount of material used in packaging) (Beattie, 2019). That example of package material reduction is a clear example on how the pillars are always "holding hands" (in this case, the environmental and economic one).

From a more technical point of view, when talking about the environmental pillar, it is important to mention the Environmental Life Cycle Assessment (E-LCA), since that methodology will be used when assessing the environmental impact of the case studies. Norris, Norris, Cavan, & Benoit (2016) claim that the LCA methodology was developed in the late 1960's and it was first standardized in 1997 by ISO 14040 (ISO, 2006a). The history of this technique is quite recent, which suggests that its development is still on an early stage and there is room for growth. The aim of this technique is to quantify the environmental impacts of a product/service over its lifetime (that is why the name of the methodology is "***life cycle*** *assessment*") – which include the raw materials extraction, the production stage, the distribution, use and lastly the end-of-life (disposal, recycling, etc.) (Norris et al., 2016). Lastly, the way this methodology works is by aggregating the inputs and outputs of resources/emissions/water/etc. into environmental impacts such as global warming, land use, resource depletion, among others.

2.1.3 Social pillar

The last and most recent pillar is the social one. This dimension is related to the wellbeing of the corporation's stakeholders. A key idea behind this pillar is that the businesses treat their employees in a fair manner (for example, give them reasonable benefits, maternity and paternity benefits, give access to learning and development opportunities, flexible scheduling, etc. (Beattie, 2019)). The examples given are some of the things that companies can do to improve their employees' welfare and develop a healthy engagement between both parties. Another relevant element is the surrounding community. Towards the community, businesses are encouraged to have a giving position: this includes initiatives like fundraising, sponsorship, scholarship, and investment in local projects (Beattie, 2019); these are some actions that companies can have which help increasing the community engagement and build and healthy relationship between them. Additionally, it is also important for a company to analyse its supply chain and understand the social influence that its partners are having in their circles of activity: for instance, if there is any child labour happening in any of the supply chain entities (raw materials providers, manufacturers, distributors, end product sellers, etc.); if every worker is being fairly paid; if the work environments are all safe; among others. These are some of the concerns that companies should have and whose purpose is for them not to look only to their part of the process, but also to have an open eye for the supply chain as an all. The positive side is that companies are showing an increasing social awareness and taking a global social approach on a supply chain level (Beattie, 2019). A good way to approach this problem is by using the Life Cycle Assessment methodology, since it takes a broad look to the full life cycle of the product/service/process.

So, regarding the LCA methodology, when it comes to E-LCA, with exception of the impact category "*Human Health*" (which takes into account chemicals that are released to the environment and that indirectly affect people), the overall social wellbeing of a product/service/process is not taken into consideration (Norris et al., 2016). So, to fight that flaw, Social Life Cycle Assessment appears as an instrument that evaluates the social impacts throughout the life cycle of the product, service, or process. This newer technique assesses the social impacts associated with all stages of product's life such as the raw materials extraction, production, consumption, disposal, etc. Therefore, the idea of this tool is to analyse de social impact of all the entities that are related to the supply chain of the product (including the influence that this product has on the workers, community, consumers, among others). Some examples of concepts that are covered in the S-LCA are the worker's rights, community development, consumer protections, and societal benefits. The officialization of S-LCA dates the year 2009, when after a five-year process with participation of over 70 international experts, the United Nations Environment Program (UNEP) and the Society of Environmental Toxicology and Chemistry (UNEP/SETAC) Life Cycle Initiative published the Guidelines for Social Life Cycle Assessment of Products (The Guidelines) (Norris et al., 2016).

2.2 Chapter conclusion

Sustainability is an ancient concept with a long history. However, its major developments occurred in the 20th and now in the 21st century. As Spindler (2013) says, the 21st century has been chosen as the "*century of sustainable development*". The topic has become an extremely relevant theme to the whole World and a huge matter of discussion by major companies and organizations, as well as a subject of study by the scientific community.

The sustainability concept can be divided into three pillars: economic, environmental, and social. In the present study, only the two last ones are a matter of study. One of the reasons for opting for these two dimensions is because they are the least studied ones, which reveals a need for more development and analysis of these two pillars combined. As Santos et al. (2019) mention in their review article, from the 104 papers that they studied, 53 are only focused in one sustainability pillar, 33 are focused in two pillars and 18 are focused on the three pillars. Figure 2, elaborated by the authors (Santos et al., 2019), besides showing the distribution previously mentioned, it also reveals that only one article assesses the environmental and the social pillar together. This enhances the thesis that these two pillars need to be studied and there is a deficiency in the literature when it comes to assessing the combination of these two dimensions. Additionally, towards the present chapter, two methodologies were introduced, which suit the problem under study: E-LCA and S-LCA. In other words, these are the same methodology (Life Cycle Assessment), applied to two dimensions of sustainability – environmental and social. Hence, for a matter of consistency and harmony, it was opted to use this methodology when assessing the environmental and social impacts of the products under study.

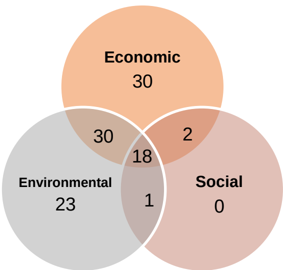

Figure 2 - Distribution of the 104 papers studied by Santos et al. (2019) according to the sustainability pillar studied

3. State-of-the-art

In this chapter, the literature review is presented which is focused on the concepts needed during this work. As mentioned and explained in the previous chapter – Chapter 2 –, sustainability lays in three different pillars: **economic**, **environmental,** and **social**. Figure 3 illustrates the three dimensions and intends to represent the fact that they are all connected and should be in harmony.

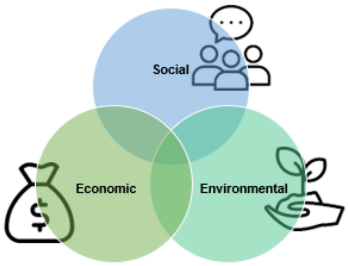

Figure 3 - Three dimensions of sustainability

The first dimension, the economic one, has several indicators that can be used to measure the economic performance of an organization in a straightforward way (for example revenues, costs, profit, etc.). However, concerning the other two dimensions, the situation is more complex since there are no direct indicators that can measure their performance. For the present study, only the last two dimensions (environmental and social) will be studied since they are the least explored ones and therefore they require more development and need to be studied more in order to get to the same level of solid development as the economic pillar. That being said, life cycle assessments (LCA) appear as a way to measure, in a methodical and structured way, the environmental and social impacts of a product or service's life cycle.

According to the standards recommended by the International Organization for Standardization (ISO), such as ISO 14040 and ISO 14044 (ISO, 2006a, 2006b), the Life Cycle Assessment methodology (which includes both environmental LCA and social LCA) includes four main steps: 1) Goal and scope definition, 2) Inventory analysis, 3) Impact assessment and 4) Interpretation. Figure 4 represents the four steps mentioned, that are common to the two methodologies. Besides that, it is also possible to observe in Figure 4 that the interpretation step should be performed simultaneously with the others; Figure 4 also indicates some examples of direct applications of this methodology.

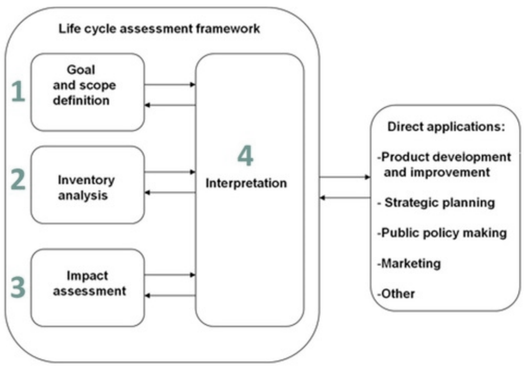

Figure 4 – Life cycle assessment framework (image from (Circular Ecology Ltd, 2020))

In terms of this chapter's structure, firstly, the concept of Environmental Life Cycle Assessment (E-LCA) is reviewed, as well as its methodology (Section 3.1). In the second phase – Section 3.2 – the focus is on the Social Life Cycle Assessment (S-LCA) and the structure is similar. In both cases, after the exposition of the methodologies, specifications for cork and bioenergy are exposed, in agreement with the survey of the existing literature on the subject (in Subsection 3.1.1 the E-LCA is applied to cork and in 3.2.1 is the S-LCA applied to the same product; Subsection 3.1.2 exposes the application of E-LCA to forest bioenergy and later on, Subsection 3.2.2 analyses the articles that apply S-LCA to forest bioenergy). Lastly, Section 3.3 presents the main conclusion gathered throughout this chapter.

3.1 Environmental Life Cycle Assessment

Environmental Life Cycle Assessment (E-LCA) is a useful tool for the evaluation of the environmental impacts of a product, process or service throughout its life cycle (Demertzi, Dias, Matos, & Arroja, 2015). Apart from identifying the environmental impact, the E-LCA technique also allows identifying improvement opportunities, which may drive to more sustainable solutions (Zabalza Bribián, Aranda Usón, & Scarpellini, 2009). This evaluation is carried out following specific standards recommended by the International Organization for Standardization (ISO), such as ISO 14040 and ISO 14044 (ISO, 2006a, 2006b). The E-LCA methodology follows four steps:

1. **Goal and scope definition** – this stage includes the explanation of the reason for executing the Environmental Life Cycle Assessment, the clarification of the product/service (and the corresponding functional unit[2]), the clear definition of the life cycle and the presentation of system boundaries (PRé Consultants, 2019). The system boundaries[3] to be determined are in terms of entities, time and location. Here, it is also important to determine the depth of the study, as well as its limitations and expected results, to be able to compare this expectations with the results obtained by the end of the analysis (Demertzi, Dias, et al., 2015). Some examples of the most common system boundaries (in terms of entities) are designated cradle-to-grave and cradle-to-gate. For instance, the term "cradle-to-grave" means that the boundary of the system will start in the "cradle" and end in the "grave", including these stages. The "cradle" entity represents the very beginning of the product/process/service under study; it can be, for example, the stage of harvesting a tree to collect raw material for a cork product. The "grave" stage will be the end-of-life of the product/service/process, for example throwing

[2] The Functional Unit (FU) is defined as "*the quantified performance of a product system to be used as a reference unit*" (ISO, 2006a). Thus, this unit is the basis of all calculations: it is the unit for which the results will be presented. It provides a reference to which the inputs and outputs are related (Demertzi, Dias, et al., 2015). Besides that, it is also a useful tool to perform comparisons: the results of different analyses can be compared more easily when they use the same functional unit.

[3] The boundaries referring to entities have the goal to set the limit within which the study will be carried out. The processes or entities inside this limit will be the only ones considered among the other E-LCA steps. Both time and location boundaries consist of problem's contextualization: specifying the time period and the geographic location to which the E-LCA is valid.

to trash a product and what it will happen until it disappears. The other system boundaries designations (still in terms of entities) work using the same logic: they include the stages X and Y at the extremities of "to" (in "X-to-Y"), and all the entities in between stages X and Y. There are exceptions, and in those cases, it is specified which entities are included in the system boundary.

2. **Inventory analysis** – also known as Life Cycle Inventory (LCI), this step is focused on the identification of raw materials necessary in the production stage, water, energy usage and emissions that occur during life cycle (Demertzi, Dias, et al., 2015; La Rosa, Recca, Gagliano, et al., 2014). In other words, here the emphasis is in the quantification of all the input and output flows of the system under study (La Rosa, Recca, Summerscales, et al., 2014). These flows must be quantitatively related to the functional unit chosen in the previous step. There are some databases that already have the information needed and organized, to where one can access and obtain this information. Some examples of databases are Econinvent, USDA, ELCD, etc.

3. **Impact assessment –** it can also be called Life Cycle Impact Assessment (LCIA) and here, the data gathered in the previous step is converted into potential environmental impacts (Demertzi, Dias, et al., 2015). Impact assessment can be either performed by mid- or endpoint approach. The midpoint approach is known as problem-oriented approach and its impact categories translate real phenomenon-based environmental themes (for example: climate change, acidification, etc.) (Muthu, 2014). The second approach mentioned is also known as damage-oriented approach, and the impact categories are translated into major concerns such as human health, natural resources, ecosystem quality, among others. In this step, there are several methods that can be used, like ReCiPe, CML, IMPACT, TRACI, among others. Also, there are some software that help assess E-LCAs, such as SimaPro, GaBi, OpenLCA, etc. Figure 5 illustrates, with a practical example, the differences in the LCIA methodology when assessing with mid- and endpoint method.

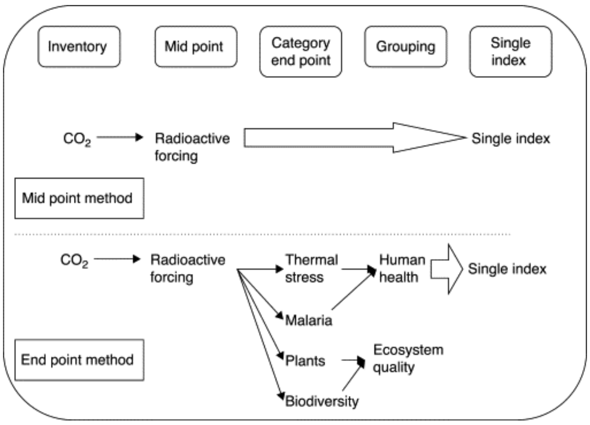

Figure 5 – Differences between mid- and endpoint approaches (image from Muthu (2014))

According to ISO (2006a), LCIA can be subdivided in three mandatory steps:

3.1. **Selection and identification of impact categories** – to start the LCIA phase, a selection and definition of relevant environmental impact categories that meet the goal and scope of the E-LCA study must be done;

3.2. **Classification** – after clearly defining the impact categories, the following procedure is to assign the LCI results to these impact categories;

3.3. **Characterization** – this step starts by defining the characterization factors, that will tell the relative contribution of each LCI result to the corresponding impact category. To calculate the characterized indicator of the impact category j, one must follow Equation 1:

$$S_j = \sum_i C_{i,j} . E_i \qquad (1)$$

S_j = Characterized indicator of the impact category j

$C_{i,j}$ = Characterization factor for the E-LCA result i, in the impact category j (it means, what is the level of impact in category j, caused by the emission of component i)

E_i = Mass or energy flow of component i of the LCI

Besides these three steps, there are more three **optional** stages:

3.4. **Normalization –** to enable the comparison between factors, the characterized indicator of impact categories is adjusted to a common reference. There is a reference value for every impact category, and to find the normalized indicator for the impact categories, this value must be known. With that information, then it is only necessary to divide the indicator of the impact category by its reference value, as it shows the Equation 2:

$$N_j = \frac{S_j}{R_j} \qquad (2)$$

N_j = Normalized indicator of impact category j

S_j = Characterized indicator of impact category j

R_j = Reference value of impact category j

3.5. **Grouping** – this stage is only performed when using the endpoint approach. Here, the impact categories are assigned to sets, which will facilitate the interpretation of results that are related to big areas of concern;

3.6. **Weighting** – the purpose here is to give different weights to the impact categories, to reflect their relative importance in the globality of the study. After deciding the individual weight of each impact category, one will multiply these weights by their normalized value (Equation 3) and then summing up the weighted indexes of all impact categories and achieve the single score (Equation 4).

$$W_j = \Omega_j N_j \quad (3)$$

Ω_j = Weight of impact category j

N_j = Normalized indicator of impact category j

W_j = Weighted index of impact category j

$$SS = \sum_j W_j \quad (4)$$

SS = Single score

W_j = Weighted index of impact category j

4. **Interpretation –** the results obtained in Steps 2 and 3 are evaluated and validated. Only after that procedure, conclusions can be drawn. Always keeping in mind the assumptions used among all the E-LCA process (Demertzi, Dias, et al., 2015). It is also in this final stage that a critical review of the E-LCA is performed, including realizing the limitations of the study as well as understanding the relationship between the E-LCA phases (ISO, 2006b). The conclusions taken here are aligned with the goal and scope of the E-LCA defined in Step 1 and answer some questions proposed there. It is important to reflect about the expected results and how they are similar or not to the actual results obtained. In this step, some deeper analysis can be performed; such as Pareto analysis (for example, trying to understand which are the most impactable processes of the life cycle), sensitivity analysis, scenario analysis, etc.; finding some gaps and mistakes that can be fixed along the life cycle of the product/service/process; presenting solutions and better line of action; there are many other possible conclusions, and the important is to have critical thinking and explore the E-LCA results.

3.1.1 E-LCA applied to cork products

In the past recent years, it is noticeable an increase in the number of E-LCA studies related to cork. Cork oak forests have the potential to avoid desertification, to prevent wildfire and to be the habitat for many plants and animals (biodiversity conservation), including many rare and endangered species such as the Iberian Lynx (La Rosa, Recca, Summerscales, et al., 2014; Tártaro, Mata, Martins, & Esteves da Silva, 2017). With the realization of the environmental potential of cork products, more people are dedicating their time to studying the environmental impacts of these products. Besides all these environmental factors, this industry also generates economic revenues and allows the development in rural areas with the generation of jobs (La Rosa, Recca, Summerscales, et al., 2014). In specific these last reasons will be more relevant to the following subsection about Social Life Cycle Assessment (Subsection 3.2.1).

After the clarification of pertinent concepts and the introduction about the cork industry, the articles referring to cork are now the subject of analysis. The platform of research used was ScienceDirect and the keywords were: cork AND "life cycle assessment". At the time of the final research, there was a universe of 368 articles with this set of keywords. The first restriction was considering only the most recent articles - from 2014 until 2019, inclusive, until the date of research (which included 252 articles). The articles not related to cork or not performing a proper environmental life cycle assessment were also excluded. Therefore, the final set of articles relevant to the present study includes 13 articles.

Table 1 contains a summary of this set of articles. The column "*Country*" refers to the country of the case study. The "*Method*" one contains the method used in the LCIA step. The "*Functional Unit*" column is self-explanatory. The next one, "*Boundary*", is related to the entities' boundary considered in the system subject to study. The last column has the number of midpoint categories evaluated.

The articles on Table 1 that have no information except in the Country column are review articles. In other papers, the columns with no information are due to lack of information.

Table 1 - Summary of the most relevant articles related to E-LCA studies applied to cork industry

Reference	Country[4]	Method	Software	Functional Unit	Boundary	Midpoint categories
(La Rosa, Recca, Gagliano, et al., 2014)	Spain	CML	SimaPro	Other	Cradle-to-grave	9
(La Rosa, Recca, Summerscales, et al., 2014)	Italy	CML	SimaPro	Other	Cradle-to-manufacture	10
(Pargana, Pinheiro, Silvestre, & De Brito, 2014)	Portugal	CML	SimaPro	Mass	Cradle-to-gate	6
(Demertzi, Dias, et al., 2015)	Portugal	ILCD	-	Mass	Consumer-to-grave	5
(Demertzi, Garrido, Dias, & Arroja, 2015)	Portugal	ILCD	-	Area	Cradle-to-gate	11
(Demertzi, Paulo, Arroja, & Dias, 2016)	Portugal	-	-	Mass	Cradle-to-grave	1
(Demertzi, Silva, Neto, Dias, & Arroja, 2016)	Portugal	ILCD	-	Other	Cradle-to-gate	11
(Sierra-Pérez et al., 2016)	Spain	CML	SimaPro	Mass	Cradle-to-gate	8
(Demertzi, Sierra-Pérez, Paulo, Arroja, & Dias, 2017)	Portugal	ILCD	-	Area	Cradle-to-gate	11
(Tártaro et al., 2017)	Portugal	-	SimaPro	Volume	Cradle-to-gate	1
(Garcia-Ceballos, de Andres-Díaz, & Contreras-Lopez, 2018)	Spain	CML	SimaPro	Area	Cradle-to-grave	6
(Sierra-Pérez, García-Pérez, Blanc, Boschmonart-Rives, & Gabarrell, 2018)	Portugal and Spain	ReCiPe	SimaPro	Area	Cradle-to-gate	11
(Sierra-Pérez, Rodríguez-Soria, Boschmonart-Rives, & Gabarrell, 2018)	Spain	CML	SimaPro	Area	Cradle-to-gate	6

Through the analysis of Table 1, it is possible to draw some conclusions about the geographical distribution of the studies carried out in this scope (see Figure 6). 57% of the articles under analysis were carried out in Portugal or about a Portuguese case study. The fact that Portugal produces around 100.000 tons of raw cork per year (more than half of the global raw cork

[4] Country - this column contains the country from where the data was collected (the case study location). If there is no concrete information about the geographical location of the case study, the country column will be referring to the article's country of origin.

production (APCOR, 2018)) might be a contribution to the number of studies carried out in this country. Next, Spain, which accounts for 36% of the total share of articles. This is an expected result, as the Iberian Peninsula is a very relevant area in what concerns the production of cork, Portugal and Spain together gather more than 50% of the total worldwide area of cork oak forests. Therefore, it makes sense that it is in this same geographical area that studies of cork's E-LCA are focused on. Figure 6 illustrates the geographical distribution of the articles analysed and Figure 7 shows the most common boundaries used in the articles studied.

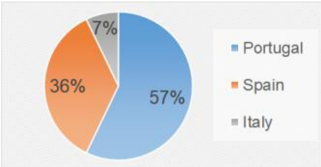

Figure 6 - Geographical distribution of the articles (cork E-LCAs)

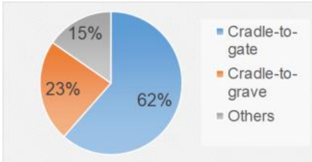

Figure 7 - Boundaries considered in the study (cork E-LCAs)

In terms of the borders, the most frequently used ones are cradle-to-gate and cradle-to-grave. As one can see in Figure 7, most articles (about 62%) opt for a cradle-to-gate approach. In the next position, the cradle-to-grave boundary shows up. This approach is more complete since the border is more comprehensive.

Another observable trend is related to the method used in the various E-LCA studies. The dominant method is CML, representing about 46% of this universe of articles. Secondly, ILCD appears with a percentage of 31%.

In terms of the software used, the only one mentioned is SimaPro.

Regarding the impact categories, the most used ones (both categories appear in 11 papers) are ozone layer depletion potential (with some variations in the given name) and climate change (either appearing under the name "*climate change*" or "*global warming potential*"). In 10 articles, authors opt for using "*acidification potential*" in the group of categories. Next, "*photochemical ozone creation potential*" appears in nine of the articles. In six of the articles, the authors chose "*eutrophication potential"* when performing the impact assessment. Five of them evaluate "*abiotic depletion*" and "*freshwater aquatic ecotoxicity*". Another category found relevant to some authors is "*human toxicity*". For example, Demertzi, Garrido, et al. (2015) opted by dividing these impact categories into two others: "*human toxicity cancer effects*" and "*human toxicity non-cancer effects*". Not only these authors, but also others picked these same specifications, while some used only the "*human toxicity cancer effects*" one. The following impact categories in the ranking of most used ones are: "*mineral resource depletion*", "*fossil resource depletion",* "*cumulative energy demand*" and "*marine eutrophication*" (all of them are used in four articles).

The previous impact categories are the ones that gather more consensus. There are categories not so used, like for example: "*terrestrial ecotoxicity*", "*marine ecotoxicity*", "*terrestrial eutrophication*", and "*freshwater eutrophication*". Demertzi, Paulo, et al. (2016) and Tártaro et al. (2017) calculate only the carbon footprint of cork products. Sierra-Pérez et al. (2016) decided to divide "*abiotic depletion*" into two categories: "*abiotic depletion potential for non-fossil resources*" and "*abiotic depletion potential for fossil resources*". Lastly, Sierra-Pérez, García-Pérez, et al. (2018) used four categories that none of the others did: "*terrestrial acidification*", "*water depletion potential*", "*metal depletion potential*", and "*fossil depletion potential*"; and with these four, the set of all the impact categories used in the papers analysed is concluded.

Figure 8 sums up the most used types of functional units.

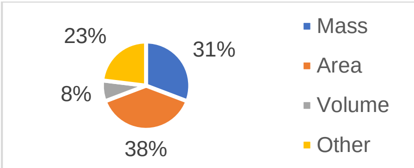

Figure 8 - Type of functional unit used in the studies (cork E-LCAs)

The most used one, as one can observe, is the area one. For example, the product that Demertzi, Garrido, et al. (2015) studied was a cork floating floor, and the functional unit (FU) used in their study was one square meter ($1\,m^2$) of final product. Secondly, the next FU is the mass. An example of this functional unit is the one used in the article of Sierra-Pérez et al. (2016): "*The functional unit (FU) used in this LCA study is defined as the mass (kg) of insulation board with an area (A) of 1* m^2 *that provides a thermal resistance R-value of 1 K/W*". The category "*Other*" also gathers a significant percentage of articles (23%) and an example of what kind of FU this category represents, the article by La Rosa, Recca, Summerscales, et al. (2014) uses the following functional unit: "*eco-sandwich panel sized (0.400 x 0.400 x 0.02 m)*".

Lastly, it is done an overview to the cork products that are under study in the papers reviewed, simultaneously with an interpretation of the results obtained in these articles (Step 4 of the E-LCA methodology). The thermal insulation material is the most studied product, being the target of eight articles (around 61,5% of the total). Cork stoppers come next, and they are used in two articles only. Then, some other cork products that are also studied are: expanded cork slab and granules, cork floating floor and agglomeration. All these last products appear in one paper each.

Sierra-Pérez et al. (2016) are one of the eight article's authors that apply the E-LCA methodology to thermal insulation material. They justify their choice based on the fact that "*The market for insulation material is playing a crucial role in Europe's energy transformation, due to its influence on energy consumption in buildings. The introduction of renewable materials for thermal insulation is recent, and little is known so far about its environmental implications.*". The fact that little is known about this issue with relevance in Europe, consists the main reason why that study was performed. Some of the conclusions gathered are: the use of natural insulation materials, such as cork, does not necessarily imply a reduction of environmental impacts; the most influential stage is the manufacturing stage; the most influential inputs are the transport (during all life cycle) and the electricity and diesel in the manufacturing stage (Sierra-Pérez et al., 2016). Besides that, the authors also identified some strategies to reduce the environmental impact, such as acquire local raw cork (in order to reduce transportation), improve the efficiency and productivity of manufacturing processes and also improve the product design to help increase its market share.

Additionally, their last conclusion was that the inclusion of biogenic carbon contained in forest-based building materials affects the global warming potential (climate change) results considerably.

Demertzi, Dias, et al. (2015) study the end-of-life of natural cork stoppers and affirm that "*An important aspect of sustainable development is the implementation of effective and sustainable waste management strategies.*". So, for that reason and because in the literature there are no other E-LCA that study the end-of-life of cork products, they think that this analysis is relevant. The three different options considered by the authors were incineration, landfilling, and recycling. The results obtained show that either incineration or recycling can be the best option, when considering different impact categories. However, the landfilling alternative does not present the best performance in any of the impact categories. One last important note that Demertzi, Dias, et al. (2015) refers is that it is important to include in the E-LCA a detailed description about all the assumptions when including the end-of-life stage. Since this stage is highly sensitive and there are several parameters that can significantly influence the results, as they proved with the sensitivity analysis performed.

3.1.2 E-LCA applied to forest bioenergy

The articles referring to forest bioenergy are now the subject of analysis. The platform of research used was also ScienceDirect and the keywords were: bioenergy AND forest AND "life cycle assessment". At the time of the final research, there was a universe of 1286 articles with this set of keywords. The first restriction applied was considering only the most recent articles - from 2014 until 2019, inclusive, until the final date of research (which included 821 articles). The articles not related to bioenergy from forest residues or not performing a proper environmental life cycle assessment were excluded (with exceptions made to review articles). Therefore, the final set of articles relevant to the present study includes 25 studies (Table 2).

The meanings of each column of Table 2 are the same as in Table 1.

Table 2 - Summary of the articles related to E-LCA studies applied to forest bioenergy industry

Reference	Country	Method	Software	Functional unit	Boundary	Midpoint categories
(Röder, Whittaker, & Thornley, 2014)	UK vs USA	CML	SimaPro	Energy (electricity)	Cradle-to-gate	1
(Adams, Shirley, & McManus, 2015)	Norway and UK	ReCiPe	SimaPro	Mass or energy[5]	Cradle-to-gate	18
(Cambero, Hans Alexandre, & Sowlati, 2015)	Canada	IMPACT	SimaPro	Other	Cradle-to-grave	1
(Giuntoli, Caserini, Marelli, Baxter, & Agostini, 2015)	EU	ILCD	GaBi	Thermal energy	Cradle-to-gate	4
(Morales, Aroca, et al., 2015)	Chile	ReCiPe	SimaPro	Volume	Cradle-to-gate	12
(Morales, Quintero, Conejeros, & Aroca, 2015)	Chile	-	-	-	-	-
(Patel, Zhang, & Kumar, 2016)	Canada	-	-	-	-	-

[5] In Adams, Shirley, & McManus (2015), the functional unit considered can be either of mass (1 ton) or of energy (1 MJ). When analysing the nature of functional units, this article will appear in both mass and energy categories.

Table 2 - Summary of the articles related to E-LCA studies applied to forest bioenergy industry (Continuation)

Reference	Country	Method	Software	Functional unit	Boundary	Midpoint categories
(de la Fuente, Athanassiadis, González-García, & Nordfjell, 2017)	Sweden vs Canada	ReCiPe	SimaPro	Mass	Cradle-to-gate	6
(Mahbub et al., 2017)	Canada	-	-	Energy (heat)	Cradle-to-gate	3
(Muazu, Borrion, & Stegemann, 2017)	Nigeria	-	-	-	-	-
(Abbas & Handler, 2018)	USA	CED	SimaPro	Mass	Cradle-to-factory[6]	2
(Ayer & Dias, 2018)	Canada	CED	OpenLCA	Mass	Cradle-to-gate	6
(Brander, 2018)	UK	-	-	-	-	-
(da Costa, Quinteiro, Tarelho, Arroja, & Dias, 2018)	Portugal	ILCD and ReCiPe	-	Energy (electricity)	Cradle-to-gate	7
(de la Fuente, Bergström, González-García, & Larsson, 2018)	Sweden	ReCiPe	SimaPro	Mass	Manufacturing-to-gate	6
(Ganguly et al., 2018)	USA	TRACI	SimaPro	Energy	Cradle-to-grave	8
(Havukainen, Nguyen, Väisänen, & Horttanainen, 2018)	Finland	CML	GaBi	Energy (heat and electricity)	Manufacturing-to-gate and Manufacturing-to-grave	3
(H. Liu, Huang, Yuan, Yin, & Wu, 2018)	China	-	-	-	-	-
(Li, Wang, & Yan, 2018)	China	-	-	-	-	-
(Roos & Ahlgren, 2018)	Sweden	-	-	-	-	-
(Ruiz, San Miguel, Corona, & López, 2018)	Spain	ILCD	SimaPro	Energy	Cradle-to-grave	11
(Tagliaferri, Evangelisti, Clift, & Lettieri, 2018)	UK	CML	GaBi	Energy (electricity)	Cradle-to-gate	9
(Beagle & Belmont, 2019)	EU vs USA	CML	OpenLCA	Energy (electricity)	Cradle-to-gate (excludes pelleting)	1
(Buonocore, Paletto, Russo, & Franzese, 2019)	Italy	ILCD	-	Thermal energy	Cradle-to-gate	8
(W. Liu, Zhu, Zhou, & Peng, 2019)	China	GWP_{bio}	OpenLCA	Area	Cradle-to-grave	1

Figures 9 and 10 help understand some statistics of the article's reality. A more detailed analysis of these two figures is presented below.

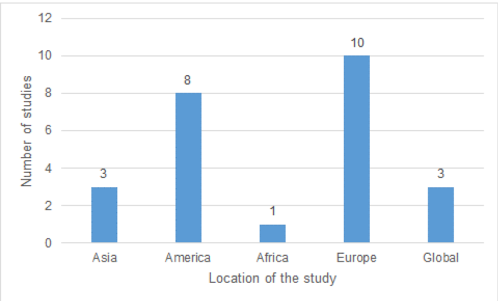

Figure 9 - Location of the studies (forest bioenergy E-LCAs)

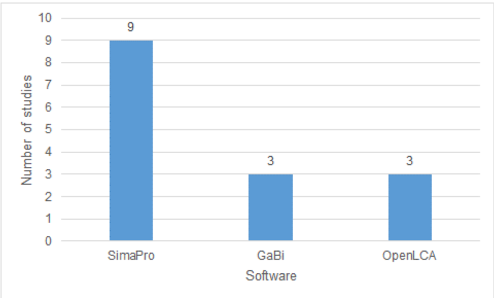

Figure 10 - Software used in the studies (forest bioenergy E-LCAs)

In Figure 9 are represented the locations of the 25 papers. The locations are grouped in continents. The "*Global*" category includes studies that are not comprised in any of the other continents represented (for example in case of a comparison between the United States of America and the European Union (Beagle & Belmont, 2019)).

[6] It englobes the harvesting processes and the transportation to the factory for further transformations, but these transformation processes are excluded from the system boundaries.

European Union (EU) has programs to support and promote bioenergy-related research and technology development (Bacovsky, Ludwiczek, Pointner, & Kumar Verma, 2016). Hence, Europe is the continent where most of the studies are performed, with a total of ten papers. The most relevant regions in Europe in terms of quantity of studies are the United Kingdom and Nordic countries (there are four studies made in the UK and five in Nordic countries – such as Sweden, Finland, and Norway). According to statistic data from IEA Bioenergy[7] (Bacovsky et al., 2016), Sweden and Finland are among the countries with the highest percentage of bioenergy in the total primary energy supply in the year of 2014, along with Brazil, Denmark, and Austria. Finland is the second country with the biggest share of bioenergy, right after Brazil, with more than 25% of bioenergy usage in primary energy supply. For those reasons, makes sense that these countries invest in knowledge about this topic. The three articles that are displayed in the Asian continent are all from China. In America, half of the papers are from Canada and the other half from USA.

Similarly, to what happens with cork, Figure 10 reinforces that the most used software to assess E-LCA studies is SimaPro (with a percentage of 60%). Here, there are also two other software showing up: GaBi and OpenLCA. Both are used in 20% of the papers analysed.

In Figure 11 the functional units are organized in five big groups: volume, mass, area, and energy; according to their nature.

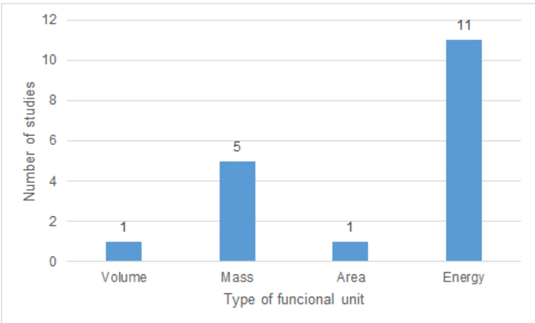

Figure 11 - Type of functional unit used in the studies (forest bioenergy E-LCAs)

Energy functional units stand out from the others because it used in 11 articles. Accordingly, most of the forestall bioenergy E-LCA studies opt for using a functional unit expressed in energetic values since bioenergy is a type of energy and it is measured in energetic units. In most cases, the functional unit expresses the amount of energy produced (either in terms of electricity, thermal energy, or others). One example of this type of FU is the article written by da Costa et al. (2018) that define their functional unit as "*the production of electricity from the combustion of eucalypt logging residues equivalent to 1 kWh delivered by the power plant to the Portuguese grid*". The

[7] "*IEA Bioenergy, also known as the Technology Collaboration Programme (TCP) for a Programme of Research, Development and Demonstration on Bioenergy, functions within a Framework created by the International Energy Agency (IEA).*" (Bacovsky et al., 2016)

second most used type of functional unit is mass, for example, "*one metric ton of green wood, with an assumed 50% moisture content, delivered to the factory gate*" (Abbas & Handler, 2018).

In terms of impact categories chosen to perform the impact assessment step, the most used one is "*climate change*", studied in 15 articles. Then, it comes "*acidification potential*" and "*photochemical ozone formation*". Both of them are used in nine articles. For example, Morales, Aroca, et al. (2015) and de la Fuente et al. (2017) specify the "*acidification potential*" category as "*terrestrial acidification*". There are four authors that agree that "*particulate matter formation*" is a relevant category to this field of study. There are several authors referring to the category "*resources depletion*" (Ruiz et al., 2018) with different divisions and names: "*ozone depletion*" (Ayer & Dias, 2018; Morales, Aroca, et al., 2015; Ruiz et al., 2018; Tagliaferri et al., 2018); "*fossil fuel depletion*" (Buonocore et al., 2019; de la Fuente et al., 2017, 2018; Morales, Aroca, et al., 2015); mineral and fossil fuel depletion (da Costa et al., 2018); "*water depletion*" (Buonocore et al., 2019; Morales, Aroca, et al., 2015); and "*abiotic depletion*" (Tagliaferri et al., 2018). "*Ecotoxicity*" (Ganguly et al., 2018; Ruiz et al., 2018) is also a pertinent category and also has various subcategories, among them are: "*terrestrial ecotoxicity*" (Morales, Aroca, et al., 2015; Tagliaferri et al., 2018); "*freshwater ecotoxicity*" (Buonocore et al., 2019; Morales, Aroca, et al., 2015; Tagliaferri et al., 2018); and "*marine ecotoxicity*" (Morales, Aroca, et al., 2015). Another matter of concern is "*eutrophication*" (considered by five articles as an impact category to evaluate). The two partitions of this last category are "*freshwater eutrophication*" (da Costa et al., 2018; de la Fuente et al., 2017, 2018; Morales, Aroca, et al., 2015) and "*marine eutrophication*" (de la Fuente et al., 2017, 2018; Morales, Aroca, et al., 2015). "*Human toxicity*" was assessed in four articles (Buonocore et al., 2019; Morales, Aroca, et al., 2015; Ruiz et al., 2018; Tagliaferri et al., 2018), while for example the "*respiratory effects*" category was only assessed in two studies (Ayer & Dias, 2018; Ganguly et al., 2018). Ganguly et al. (2018) considered "*smog*", "*carcinogenic*" and "*non-carcinogenic*" categories while assessing the E-LCA study. Finally, the only two categories missing are "*ionizing radiation*" and "*land use*" that were both picked by Ruiz et al. (2018).

The method most used in these articles is ReCiPe, used in five of them (Adams et al., 2015; da Costa et al., 2018; de la Fuente et al., 2017, 2018; Morales, Aroca, et al., 2015). CML and ILCD were both used in four articles. These three methods are also common to the ones used in E-LCA applied to cork, but the following ones only appear when searching E-LCA applied to forest bioenergy: CED, IMPACT, TRACI and GWP_{bio}. The last one, GWP_{bio}, is mentioned by W. Liu et al. (2019) that performs a comparison between new and conventional methods and they say that "*significant high life cycle CO_2 emission was found in comparison to the conventional method*", when using the GWP_{bio}.

The bioenergy is generated from organic matter – called biomass. In this particular case, since it is forest bioenergy, the biomass comes from forest residues. So, regarding the product studied by the papers analysed, some articles use biomass coming from wood chips and other from forest harvest residues.

To finish this subsection, a brief analysis of the most relevant ideas about the review articles is performed. First, Morales, Quintero, et al. (2015) analyse more than 100 case studies in order to compare the environmental impacts of first generation bioethanol and gasoline with lignocellulosic bioethanol. They concluded that lignocellulosic bioethanol represents a reduction in GHG (greenhouse gas) emissions and a positive energy balance, when compared to fossil fuels alternatives. The gap identified in this paper relies on the fact that impact categories like acidification and eutrophication have not been intensively reported. Secondly, Patel et al. (2016) performed a study that includes both environmental and economic pillars of sustainability. Among other conclusions and literature gaps, these authors emphasize what they consider the main limitation of E-LCAs: "*the lack of comparative assessment of different pathways based on environmental metrics*". The problem is, they say, the fact that different authors take different paths to assess the E-LCA methodology, either with different boundaries, software (that consequently have different databases), functional units, etc. Therefore, their suggestion of solution is the development of a standardized approach for a meaningful E-LCA comparison. Muazu et al. (2017) agrees with Patel et al. (2016) about the differences in the choices made when assessing E-LCA studies and their influence in terms of poor comparisons. Muazu et al. (2017) even says that the existing biomass-related E-LCAs provide insufficient and inconsistent information. Besides that, the authors refer that most of the reviewed studies attribute most of the energy use and GHG emissions to transportation, drying and densification. One more time, it is referred by other authors that "*E-LCA results exhibit strong dependency on methodological choices*" (H. Liu et al., 2018). Again, H. Liu et al. (2018) also highlight the importance of transparency in assumptions and key inputs to E-LCA model. Accordingly, this is the most recommended solution.

3.2 Social Life Cycle Assessment

Social Life Cycle Assessment (S-LCA) has been a field of study in the late years, so its development has been a target of changes and new discoveries, and studies are constantly showing up. Since it is a more recent and less explored field in comparison with E-LCA, Social Life Cycle Assessment guidelines are less explicit and might comprehend a less objective vision. In alignment with these statements, some of the uses of S-LCA are to support supply chain management, to advise about responsible purchasing strategies, to improve the design and development of new products, to improve long/term business decisions, to understand social issues in the life cycle of the product, process or system, among others (Russo Garrido, 2017).

UNEP/SETAC guidelines give directions and guidance on how to apply social life cycle assessment, but they also comment on the fact that there is the need to develop more databases and more detailed indicators for social subcategories (Mattila, Judl, Macombe, & Leskinen, 2018). According to these guidelines, S-LCA's methodology consists of four main steps (Russo Garrido, 2017):

1. **Goal and scope definition** – this step comprises several activities such as: to clarify the reasons for doing the study; clearly define the product that will be studied; set the functional unit and the activity variable[8]; establish the boundaries of the system; what stakeholders to include; decision of the impact categories; decide how it will be performed the data collection and methods used;

2. **Inventory analysis** – or life cycle inventory analysis (LCI). Here, the data is collected and organized. The data is typically gathered through questionnaires, literature review, existing instruments and/or databases (like for example the SHDB – The Social Hotspots Database or PSILCA - Product Social Impact Life Cycle Assessment); Russo Garrido (2017) reflects about the root of most social issues and, in that extent, explains why the LCI step in S-LCA is different from the E-LCA one. She says that "*While the source of impacts in E-LCA lies in the materials and energy involved at each step of the life cycle, potential social impacts do not generally originate from these same sources. There is a consensus that the majority of social impacts originate from the practices/behaviours and the economic contributions from organizations which are involved in the life cycle of the product, rather than the production processes themselves*." This explanation given by Russo Garrido (2017) clarifies why the data gathering in this stage of S-LCA is collected in monetary terms, contrary to what happens in E-LCA. Regarding the depth of the LCI step, Norris et al. (2016) says that when a bottom-up, enterprise-level approach is used exclusively, very few companies in a supply chain can be fully assessed. The level of detail is too high, and the amount of unit processes are excessive, leading to enormous amount of information to be collected. For that reason, a top-down approach is more appropriate, because it simplifies the LCI step, which can be very complex and time consuming. A good example on how to assess a top-down data collection is by using tools that contain country and sector specific statistic data. This way, the data is more accessible and so, it facilitates the process of collecting data.

3. **Impact assessment** – or life cycle impact assessment (LCIA). Social LCA can be performed resorting to two different approaches: Type I or Type II S-LCA. These two approaches differ only in the LCIA step, so their impact categories will be evaluated in different ways. The first one, also known as "*Social Performance S-LCA*", normally uses an ordinal scale[9] to quantify the impact categories (Benoit-Norris et al., 2013). This scale describes either the risk, the performance, or the degree of management. Secondly, type II S-LCA or "*Impact Pathway S-LCA*": its potential impact categories are assessed by trying to model the connection between the source of impact and its impact on human

[8] "*The activity variable is a variable representing a quantifiable activity that can be measured at each life-cycle step (or process). Hours of work are the most commonly used activity variable*." (Russo Garrido, 2017)
[9] The scale is organized in an order (it has classes that have a specific order but do not have a specific value or a range of values; there is no quantification of the difference between the classes, only their hierarchy). Examples of ordinal scales are social rank, wage rank, scales made to measure some opinion, etc.

well-being (that is why it is called "*impact pathway*" – "*causal relations which can be traced between activities and their ultimate social outcomes*" (Russo Garrido, 2017)). Both ways, the data is analysed and assessed in potential social impact categories. Furthermore, this stage can be subdivided into three sub-steps (Benoit-Norris et al., 2013):

3.1 Selection - impact categories selection and characterization methods and models;

3.2 Classification - linking inventory data to an impact category;

3.1 Characterization – determine the relative weight that each inventory item has in the impact category; calculate the result of the impact categories indicator (aggregating the weighted values – the value of the inventory item multiplied by its weight); Equation 5 expresses the calculations behind this step:

$$SHI_{cat} = \frac{\sum_{T=1}^{n}(R_{avg} \times W_T)}{\sum_{T=1}^{n}(R_{max} \times W_T)} \tag{5}$$

SHI_{cat} = Social Hotspot Index for a Category (e.g., Labour Rights, Governance, etc.)

T = Theme (e.g., Child Labour, Freedom of Association Rights)

n = Number of Themes within a Category

R_{avg} = Average Risk across the Theme

R_{max} = Maximum Risk for a Theme

W_T = Weight assigned to Theme T

4. **Interpretation** – As Russo Garrido (2017) says in her article, "*The format of S LCA results is not standardized and varies from one study to another*.", but there are still some commonalities that arise: to identify the steps/entities along the life cycle that have more potential to aggregate social impacts; identify what types of social issues are most likely to emerge in the steps/entities of the life cycle previously recognized. The results are typically presented in tables, Graedel diagrams, bar graphs, showing results per life cycle step or per impact subcategory or category. The interpretation normally focuses on explaining these results (for example using tools like the Pareto Principle, Radar Chart or trying to find some other correlations), discussing root causes, and proposing recommendations, always aligned with the goal and scope (defined in step 1) (Russo Garrido, 2017).

3.2.1 S-LCA applied to cork

When the research was assessed in ScienceDirect, with the set of keywords cork AND "social life cycle assessment", only two results showed up. One from the year of 2012 and the other from 2018. Both articles did not meet the criteria of being about cork and including a S-LCA. Thus, neither of them was considered relevant in this section.

It is fair to conclude that Social LCA applied to cork products is a field of studies not too explored yet. So, the present study aims to find new and important discoveries about this topic; and since the topic is not much studied yet, there is still a lot of knowledge and information to extract from here. Besides that, as previously referred in Subsection 3.1.1, this industry generates relevant economic revenues, provides development in rural areas and generates jobs (La Rosa, Recca, Summerscales, et al., 2014). Therefore, this constitutes good reasons to explore and study social issues in this business area and in particular about Portugal, since it is a relevant country in terms of production of raw cork (like preciously mentioned at the beginning of Chapter 3.1.1).

3.2.2 S-LCA applied to forest bioenergy

When it comes to bioenergy, the case is different and there are already a few S-LCA studies about this industry. Using the same strategy, the set of words picked was bioenergy AND "social life cycle assessment" AND forest.

Initially, the set of studies was constituted by 36 articles. The ones not related to bioenergy from forest residues or not performing a proper social life cycle assessment were excluded (with exceptions made to review articles). Therefore, the final set of articles relevant to this section includes four papers (Table 3).

Table 3 - Summary of the most relevant articles related to S-LCA studies applied to forest bioenergy industry

Reference	Country	Type	Impact categories	Database
(Macombe, Leskinen, Feschet, & Antikainen, 2013)	Finland	-	-	-
(Palmeros Parada, Osseweijer, & Posada Duque, 2017)	The Netherlands	-	-	-
(Mattila et al., 2018)	Finland	Social Performance	5	SHDB
(Fedorova & Pongrácz, 2019)	Finland	Social Performance	9	Eco-invent

Macombe et al. (2013) say that "*how to define system's boundaries in S-LCA*", and "*how to integrate E-LCA and S-LCA within the same framework*" are some problematics worth more attention, which the present study aims to study and give relevant contribution to those questions. That first study is a review article, and exposes a wide view of the situation, down in the year of 2013, of how bioenergy S-LCA studies were. The second one (Palmeros Parada et al., 2017) is also a review article, a bit more recent, that takes into consideration all three dimensions of sustainability (economic, social and environmental), their metrics and methods and also the stakeholders' perspective.

Three out of four articles are from Finland. According to Fedorova & Pongrácz (2019), the Finnish bioenergy industry is actively engaged in the EU initiative of building a sustainable bioeconomy (with the use of available local resources). With this motivation, various players in Finnish society tend to participate in different programs and studies related to the improvement of sustainable bioenergy production.

Mattila et al. (2018) resort to five impact categories: “*community infra*”, “*governance*”, “*health and safety*”, “*human rights and labor rights*”. The choice of the most important issues was made recurring to the Social Hotspots Database (SHDB).

Fedorova & Pongrácz (2019) had a different approach and divided the impacts into three major categories: “*individual wellbeing and social capital*”, “*microeconomics and community wellbeing*” and lastly, “*social acceptance and societal impacts*”. Each one of these core social components were also separated into three social indicators. The first one, “*individual wellbeing and social capital*”, is subdivided into: “*training*”; “*occupational health and safety*”; and “h*ealth hazard from emissions”*. The second component is sectioned into “*employment*”, “*regional economic development*” and “*direct economic impacts*”. “*Energy security*”, “*public opinion*”, and “*local community engagement*” are the tree social indicators of the last category.

3.3 Chapter conclusion

It became clear in the present chapter the differences between cork products and bioenergy, and of how explored those two products are in the topic of E-LCA and S-LCA. In comparison and in general mode, bioenergy has been the target of more studies along the years than cork products (both in environmental and social LCA). It is possible to draw some conclusions to the globality of E-LCA articles - cork and forest bioenergy articles all together - the most used software is SimaPro; the most common boundary is cradle-to-gate, followed by cradle-to-grave; CML is the method that most of the studies resort to; the category that is used in more articles is climate change; categories like acidification potential, photochemical ozone creation potential and ozone layer depletion potential are also amongst the most used ones.

Comparing environmental and social LCA studies, the amount of information available is much less when talking about social ones. As expected, since the second is a more recent topic, and its guidelines and rules are not so polished and well defined, which makes room for discoveries and to explore this field. As mentioned, Macombe et al. (2013) refers that the question “how to integrate E-LCA and S-LCA within the same framework” is a major issue that needs to be studied, in order to build solid conclusions and knowledge about the topic.

4. Research Methodology

This chapter presents the research methodology applied in this work. Figure 12 represents the employed methodology.

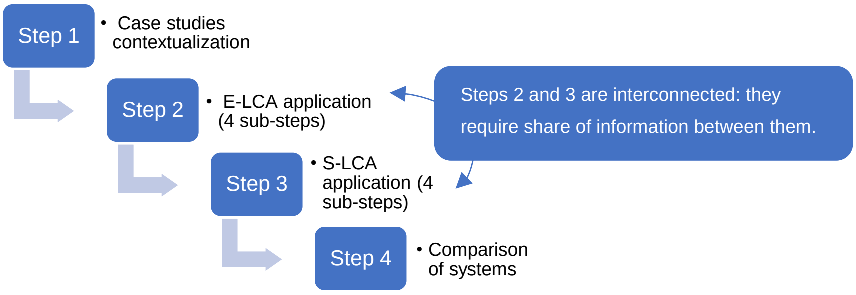

Figure 12 - Research methodology steps

The methodologies employed in each step will be explained as follows.

Step 1 – Case studies contextualization

The first step of this methodology consists of contextualizing the case studies under study. The tasks included in this step are a small introduction of each industry and a brief contextualization about the companies selected as case studies. The information studied in this step can be taken from companies' website and from the literature.

Step 2 - E-LCA application

The second step is the E-LCA application. According to ISO 14040 (ISO, 2006a), the E-LCA methodology consists of four main steps: 1) goal and scope definition; 2) inventory analysis (LCI); 3) impact assessment (LCIA); and lastly, 4) interpretation. For a better understanding, Step 2 was subdivided into four sub-steps:

Step 2.1 – Goal and scope definition for the E-LCA studies

The first step of the E-LCA methodology is to define the goal and scope of the E-LCA studies. This step includes the explanation of why both E-LCA studies are being performed (the goal), as well as the scope of the study. In the scope the products' life cycle, the systems' boundaries (physical, geographical and temporal) and the functional unit are defined. Besides that and not less important, the products under study have to be clarified (regarding their physical characteristics and purpose). The information regarding the life cycle of the products will be constructed by collecting information in the respective companies' website (Corticeira Amorim, 2015e) (Martos & Cª Lda., 2018a). The literature about the topics was also helpful, as well as the APCOR's website and reports (APCOR, 2015b).

Step 2.2 – Inventory analysis (LCI) of the E-LCA studies

Step 2.2 aims to gather the inventory data needed to proceed with the E-LCA assessments. This step's focus is on the identification and quantification of materials flows necessary in the life cycle stages, water, energy usage and emissions that occur in the physical boundaries life cycles (Demertzi, Dias, et al., 2015; La Rosa, Recca, Gagliano, et al., 2014). Hence, the output of this step is the inventory – an inventory list with all the inputs and outputs (materials, water, energy, and emissions) throughout the systems' life cycle, and these inputs/outputs are all correlated to the functional unit. These inputs and outputs are also associated to the systems' boundaries defined in the previous step.

The collection of the inventory required in this step is performed by four methods: i) by collecting information in the website of Corticeira Amorim and Omnipellets (including reports that they have available); ii) by gathering the data available in the literature (process that already started when assessing the state-of-the-art (Chapter 3) and it was continued here); iii) by using the material available in statistics websites, such as the statistics of the forest sector (or the cork and bioenergy industry also); and lastly iv), the Ecoinvent database was used to complete the life cycle inventory for general processes (Lauw, Oliveira, Lopes, & Pereira, 2017).

Step 2.3 – Impact assessment (LCIA) of the E-LCA studies

Step 2.3 starts with the decision of the LCIA method. Section 3.1 (step 3) gives several options of methods that can be used here. There are two types of LCIA methods: mid- and endpoint approach. Thus, this step seeks to select which method is a better fit for the problem under study. With the selection of the method, several outcomes will also be implicitly generated, such as the impact categories, characterization factors, mid to end factors, normalization factors, and weights.

Besides that, in order to compute the LCIA step, the use of a software is advantageous, because it will perform all the calculations needed (and explained in Section 3.1 – Step 3). Also, in that section, one can find several examples of possible software one can choose from.

With the decision of the LCIA method and the software already in place, as well as the inventory list obtained in Step 2.2, the conditions to start the impact assessment are aligned. The course of action here is to insert the inventory list in the software and to select the desired LCIA method, and then let the software perform the calculations.

The Life Cycle Impact Assessment (LCIA) converts the data gathered in Step 2.2 (the inventory list) into potential environmental impacts (Demertzi, Dias, et al., 2015). As already mentioned, Section 3.1 explains in more detail the calculations behind the following steps, which again are done by the software in use. According to ISO (2006a), LCIA can be subdivided in three mandatory steps: 2.3.1) selection and identification of the impact categories; 2.3.2) classification; and 2.3.3) characterization.

And besides these three mandatory steps, there are also three more optional ones that can be performed in case the method chosen is an end-point method: 2.3.4) normalization; 2.3.5) grouping; and 2.3.6) weighting.

So, the two main outputs of this step are the single score and the impact and damage categories (and respective values), given by the software in use.

Step 2.4 – Interpretation of the E-LCA results

The results of Step 2.3 are analysed in this step. A common characteristic of all the results is that the higher their value, the worse its environmental "degree". Some analysis that will be performed are listed below:

- Critical impact categories: The identification of the risk impact categories (the categories that show the highest values) is a common analysis and thus it is imperative to perform it. A useful tool is the Pareto analysis, also known as 80/20 Rule, which is aims to identify the critical categories. This principle states that 80% of the effects are caused by 20% of the causes;
- Critical life cycle processes: Another important point is to understand which are the most impactable processes of the life cycle. So, the identification of critical processes (the ones that impact the most the critical impact categories, identified in the previous point) is another analysis that adds value and is desirable to be accomplished;
- Environmental hotspots: Identification of the environmental hotspots among the system's life cycle. Hotspots are elements (processes' inputs or outputs) within the system under study that contribute to a certain impact category (Muñoz, Curaqueo, Cea, Vera, & Navia, 2017).
- Recommendations: If applicable, it is also in this step that the suggestions of better solutions for the life cycle processes takes place.

The conclusions taken here have to be aligned with the goal and scope of the E-LCA defined in Step 2.1 and answer some questions proposed there. It is important to reflect about the expected results and how they are similar or not to the actual results obtained.

Consequently, the outputs of this step are the conclusions of all the analysis mentioned.

Step 3 – S-LCA application

The next step is to apply the S-LCA methodology to the systems under study. UNEP/SETAC guidelines give directions and guidance on how to apply Social Life Cycle Assessments (Mattila et al., 2018). According to those guidelines and similarly to E-LCA methodology, social LCA consists of four main steps (Russo Garrido, 2017): 1) Goal and scope definition; 2) Inventory analysis; 3) Impact assessment; and lastly, 4) Interpretation. Each one of these steps are explained in detail in Steps 3.1 to 3.4, respectively.

Step 3.1 – Goal and scope definition for the S-LCA studies

This step, parallelly to E-LCA's first step, also aims to clarify the reasons for doing this study (goal definition). Secondly, in the scope definition, several activities are required to be defined: clearly define the products that will be studied; set the functional units and the activity variable[10]; define

[10] Russo Garrido (2017) explains what the activity variable is and gives an example: *"The activity variable is a variable representing a quantifiable activity that can be measured at each life-cycle step (or process). Hours of work are the most commonly used activity variable."*

the life cycle; establish the boundaries of the system; what stakeholders to include; decide about the impact categories and subcategories to include; and select the evaluation and data collection methods.

Step 3.2 – Inventory analysis (LCI) of the S-LCA studies

This step intends to collect and organize the data required for the following steps. Here, it is required to identify the prices (in USD of the year 2011) of the processes' inputs (materials/energy/water) as well as their country of origin and GTAP sector. Table 16 of Appendix A shows all the 57 existing GTAP sectors and respective code – the GTAP sectors (codes and descriptions) are the ones used in the SHDB, since they are slightly different from the original ones (which are in fact 67 and have different codes (Center for Global Trade Analysis, 2020)). Each input needs to be categorized into one of those fifty-seven sectors.

This data collection (price, origin and sector) can be performed resorting to several methods, but in this work the approaches used were through literature review, statistics platforms, websites of producers, reports of relevant entities and also with the help of existing databases such as SHDB - The Social Hotspots Database. Regarding the SHDB, Norris et al. (2016) comment on its features, which "*include: the ability to generate geographically specific supply chains models and the ability to estimate the labour intensity by economic sector of activity, systematic and consistent methodology, transparent compilation and interpretation of a large number of publicly available data, and diverse applications not necessarily specific to S-LCA.*"

The output of this step is an inventory list with the prices of the life cycle's inputs, their countries of origin and GTAP sector.

Step 3.3 – Impact assessment (LCIA) of the S-LCA studies

The input of this step is precisely the output of Step 3.2 – the inventory data with the prices, countries of origin and GTAP sector. That data is analysed and assessed in potential social impact categories. For the data conversion into social impact categories, the use of a software is beneficial. Likewise Step 2.3 of this methodology, the course of action of this step is to insert the inventory list (output of Step 3.2) in the software and to select the desired LCIA method, and then let the software perform the calculations inherent to this step. Section 3.2 gives alternatives for methods and software that can be used when assessing the present step.

This step can be subdivided into three levels (Benoit-Norris et al., 2013): 3.3.1) selection and identification of the impact categories; 3.3.2) classification; and 3.3.3) characterization. Sub-step 3.3.1, as its name indicates, aims to select the impact categories (or midpoint categories or themes) that fit the problem features. The second sub-step, 3.3.2, links the inventory data collected in Step 3.2 to the impact categories (this connection is made with the help of the activity variable – the most common one is the hours of work) . Then, the characterization step (3.3.3) calculates the indicator of each impact category. If desired, one can aggregate the impact categories into endpoint categories and then also aggregate those endpoint categories in order to obtain a single score. Section 3.2 (Social Life Cycle Assessment) of the present document provides detailed information about the calculations behind each sub-step and their purpose.

Step 3.4 – Interpretation of the S-LCA results

This is the last step in the S-LCA methodology: the interpretation of the results obtained in Step 3.3. The understanding of the outputs will be performed through several different analysis (Russo Garrido, 2017):

- Critical impact categories: To identify the risk impact categories (the ones that have the highest values) and, similarly to the analysis of the E-LCA results (Step 2.4), to analyse the application of the Pareto rule;
- Critical life cycle processes: Identification of the processes along the life cycle that have more potential to aggregate social impacts - the processes that impact the most the categories identified in the previous analysis;
- Social hotspots: To identify what types of social issues are most likely to emerge throughout the life cycle and which are the countries and elements (inputs/outputs) responsible for those social issues;
- Recommendation: To propose solutions for the problems identified, which have to be aligned with the goal and scope defined.

Step 4 – Comparison of systems

The last step of the present methodology, Step 4, aims to take a wider look at the results of Steps 2 and 3 (the E- and S-LCA application), and take conclusions regarding the systems' performance in the sustainability field. This step has the purpose to compare the results of the two systems under study. If possible, the idea is to draw conclusions about the sector they are both inserted or to understand the commonality between systems and generate broader inferences. The environmental and social comparisons follow the same structure and include:

- Impact categories comparison: the first comparison between the two CSs under analysis is performed at the midpoint level. The impact categories are compared in order to understand which CS is better and in which categories;
- Endpoint categories comparison: secondly, the comparison between case studies is performed at the endpoint level. The endpoint categories are compared in order to understand which system has a better environmental performance;
- Single score comparison: lastly, the SS is compared to conclude which CS is environmentally and socially better (inside that system's boundary and with that functional unit).

Throughout the comparison, a set of recommendations are given and general conclusions about the common sector are presented.

5. Results

The present chapter is subdivided into three main sections: 5.1 assessing the Corticeira Amorim Case Study (CS), 5.2 representing Omnipellets CS, and 5.3 comparing the case studies. The division of sections 5.1 and 5.2 is analogous. Both subsections 5.1.1 and 5.2.1 include the descriptions of the respective CS (Step 1 of the Research Methodology): firstly, these subsections start by introducing their respective industries (cork and bioenergy); and then they cover the company's mission and vision, and lastly the business units. Moving on to the next two subsections, 5.1.2 and 5.2.2, corresponding respectively to Corticeira Amorim and Omnipellets, they explore the application of the second step of the methodology (described in Chapter 4) – the E-LCA application. Then, subsections 5.1.3 and 5.2.3 are similar to the previous ones but with the S-LCA application (Step 3 of the methodology). Lastly, Section 5.3 is the application of Step 4 of the methodology – the comparison of the two CS (environmentally and socially).

5.1 Corticeira Amorim

This section assesses Corticeira Amorim CS. Subsection 5.1.1 will describe the Corticeira Amorim CS. In Subsection 5.1.2, the E-LCA is applied and in Subsection 5.1.3, it is the S-LCA application. The last two subsections are divided the same way: Subsections 5.1.2.1 and 5.1.3.1 represent the goal and scope definition (respectively of the E-LCA and S-LCA – the same applies to the following sub-sections); Subsections 5.1.2.2 and 5.1.3.2 are the LCI step; the Subsections 5.1.2.3 and 5.1.3.3 contain the LCIA step; and lastly, Subsections 5.1.2.4 and 5.1.3.4 have the interpretation of the results.

5.1.1 Step 1 - Case study contextualization

Industry contextualization

According to APCOR (2018), the Portuguese Cork Association, cork oak forests cover an area of 2.139.942 hectares, which is mainly located in the Mediterranean region (South Europe and North of Africa). This area is distributed between Portugal, Spain, Morocco, Algeria, Tunisia, France, and Italy (in a descendant order of planted area). Portugal and Spain together gather more than 50% of the total area. Portugal produces around 100.000 tons of raw cork per year, which represents more than half of the global raw cork production (APCOR, 2018). According to the World Wild Fund for Nature (WWF) (World Wildlife Fund, 2019), more than 100.000 people in southern Europe and North Africa, directly and indirectly, depend on cork oak forests (Amorim Cork Composites S.A., 2018). In Portugal, there are around 700 companies directly dependent on this economy, which involves about 8300 direct jobs and thousands of indirect ones.

Cork products are mainly intended to be exported, representing 2% of the total Portuguese exports – and most of these exports regard cork stoppers (72%). Because of all these reasons, cork oak was declared Portugal's National Tree in 2011, by the Portuguese Parliament; and it has been protected by law since the 13th century. These facts combined only reinforce the importance and influence that cork oaks represent to the Portuguese community (Corticeira Amorim, 2015a).

Corticeira Amorim is the company selected as the cork's case study. A substantial part of the information in this section was taken from the company's sustainability report of 2018. Their custom of publishing a sustainability report started in 2006, which was a pioneer practice for that time in this business sector. Besides the company's sustainability report, their website and the Consolidated Annual Report of 2018 are also one of the biggest information sources.

Mission and Vision

This company is an active player in terms of social responsibility. For instance, in the field of education, Corticeira Amorim supports several initiatives that aim to short the relationship between schools and the scientific/business community. In a wider level, the company collaborates with institutions focused on social integration (for minors at risk and elderly population), firefighter brigades, the Portuguese Anti-Cancer League (*Liga Portuguesa Contra o Cancro*), sports clubs, Bagos d'Ouro Association (which is an association dedicated to support disadvantaged children and young people in the Douro region), among others (Corticeira Amorim, 2015d). In the environmental pillar, the cork oak forests themselves have an important role. "*They support a unique and fragile ecology which constitutes a habitat for rare and endangered species. (…) Over two hundred animal species and one hundred thirty-five plant species per 1000* m^2 *find ideal conditions for survival in the cork oak forest*." (Corticeira Amorim, 2015d). Besides that, cork oak forests protect against erosion and consequently against desertification; they are important barriers against fire since they have weak combustion potential. They absorb an estimation of over 73 tons of carbon dioxide (CO_2), for every ton of cork produced, an important contribution to reducing greenhouse gas emission. An interesting fact is that cork oaks increase their ability to absorb CO_2 after they get stripped (on average, a stripped cork oak absorbs five more times CO_2 than a new cork oak); and this ability to absorb this gas is passed to the manufactured cork products (Corticeira Amorim, 2015).

In this sequence, Corticeira Amorim's Mission and Vision (Corticeira Amorim, 2015b) are also aligned with the environmental and social pillars, and they are as follows:

- Mission: "*To add value to cork, in a competitive, differentiating and innovative manner, in perfect harmony with **Nature***."
- Vision: "*To generate return on capital invested in an appropriate and **sustained** manner, with differentiation factors at the level of product and service and with a **workforce** which has the desire to succeed*."

The highlight of the company's Mission is to be competitive and innovative without dismissing the environment and Mother Nature. The fact that the company has the need to mention the Nature in their Mission is highly indicative of their concern with the environment. Again, in their Vision, they feel the need to refer to sustainability as a key factor in their goals. The word workforce applied in that context may also indicate that the company is concerned with their collaborators' wellbeing – which remits to social awareness.

Business Units

Corticeira Amorim has five business units (BUs), and these are some of their characteristics (Corticeira Amorim, 2018):

- **Raw materials** – it is inserted in the Amorim Natural Cork macro area. They have eleven industrial plants dedicated to raw materials. Since Corticeira Amorim is not a forest owner, the main purpose of this BU is to plan the purchases of raw materials (cork) and evaluate/decide about the company's supply policies (Corticeira Amorim, 2015c);
- **Cork Stoppers** – annual production of 5.500 million units and world leader in production and distribution of cork stoppers, and 4.000 million units sold per year;
- **Floor & Wall Coverings** – also world leader in production and distribution of floor and wall coverings with cork. This innovative technology in the covering industry gives better performance in both thermic and acoustic insulation, as well as more comfort while walking. Reduces the walking sound up to 53%;
- **Composite Cork** – its activities include the production of granulated, agglomerate and cork composite. Cork's natural properties, together with some other materials, create top-class solution that can be applied to the most diverse sectors (such as construction industry, footwear industry, aerospace industry, railway industry, among many others);
- **Insulation Cork** – lastly, this business unit concentrates its effort on the production of 100% natural insulation materials. As previously referred, this material has high level of thermic, acoustic, and anti-vibrating insulation, as well as extremely high durability. Lately, this solution has been increasingly used in interior design.

Cork stoppers gather around 69% of the company's sales (Figure 13).

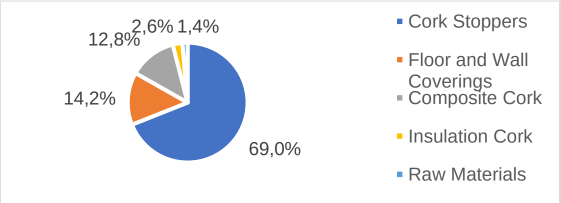

Figure 13 - Consolidated Sales by Business Unit

This business unit, besides being the first business unit to exist in Américo Amorim group, it is, in terms of consolidated sales, the most relevant BU. That is one of the reasons why the cork stoppers business unit was the BU selected to study. Besides that, as previously mentioned, Corticeira Amorim is a world leader in production and distribution of cork stoppers, so for that reason and because it is a Portuguese company, it gathers the ideal conditions to be the company of the cork's case study.

5.1.2 Step 2 – E-LCA application

This subsection consists of the E-LCA application (Step 2 in the methodology) to the production of **natural cork stoppers** by Corticeira Amorim .

5.1.2.1 Step 2.1 – Goal and scope definition

The product under analysis is the natural cork stopper (NCS) produced by Corticeira Amorim, the company described in the Subsection 5.1.1. Demertzi, Silva, et al. (2016) share some relevant numbers regarding the cork sector in Portugal: "*The Portuguese cork sector is responsible for producing approximately 40 million stoppers per day, placing them at the top (70%) of the total exports of the sector (APCOR, 2019) with natural cork stoppers having the leading role (63% of the total number of stoppers export)*". So, the fact that the natural cork stoppers have such a highlight position in the Portuguese economy, is one of the reasons why they are relevant to be studied. The goal and scope of this E-LCA are exposed below, as well as the assumptions made along the way:

Goal: The main goals are to learn about the environmental impacts of the natural cork stoppers (NCS), to compare the NCS life cycle with the pellets and to formulate conclusions about the environmental impacts of the forest sector.

Scope:

Product characteristics (APCOR, 2015b; Demertzi, Silva, et al., 2016)**:**

- Product: natural cork stoppers
- Shape: cylindric
- Length: (45 ± 1) mm
- Diameter: (24 ± 0,5) mm
- Density: 120-220 kg/m^3 (varies inside this range of values because the raw material is heterogeneous)
- Moisture: 4%-8%

Functional Unit: The quantity of product necessary to generate a revenue of 100.000 € per year (in this case study, the amount of NCS necessary to generate that revenue is equivalent to 28.166,89 kg (INE, 2018)). This was the chosen functional unit because it is a unit that makes sense to both case studies and that allows the comparison between them. The use of a more common functional unit, such as a mass unit, would be reasonable if assessing only one of these case studies. However, when comparing these two CS it does not make sense to compare them in terms of mass since they have very distinct functions and when using the same mass of product it would mean completely different things to each CS.

Boundaries: The system boundary is cradle-to-usage (Figure 14). This was the boundary chosen because it includes all the processes for which it was possible to collect information from both case studies (and since a comparison will be performed, it was important to have the same system's boundary in both CS). The time boundary is one year, and the geographical boundary is the whole World since the Corticeira Amorim's supply chain of NCS has entities in several different countries.

Life cycle: The life cycle of the natural cork stoppers is represented in Figure 14, as well as the system's boundary (cradle-to-usage).

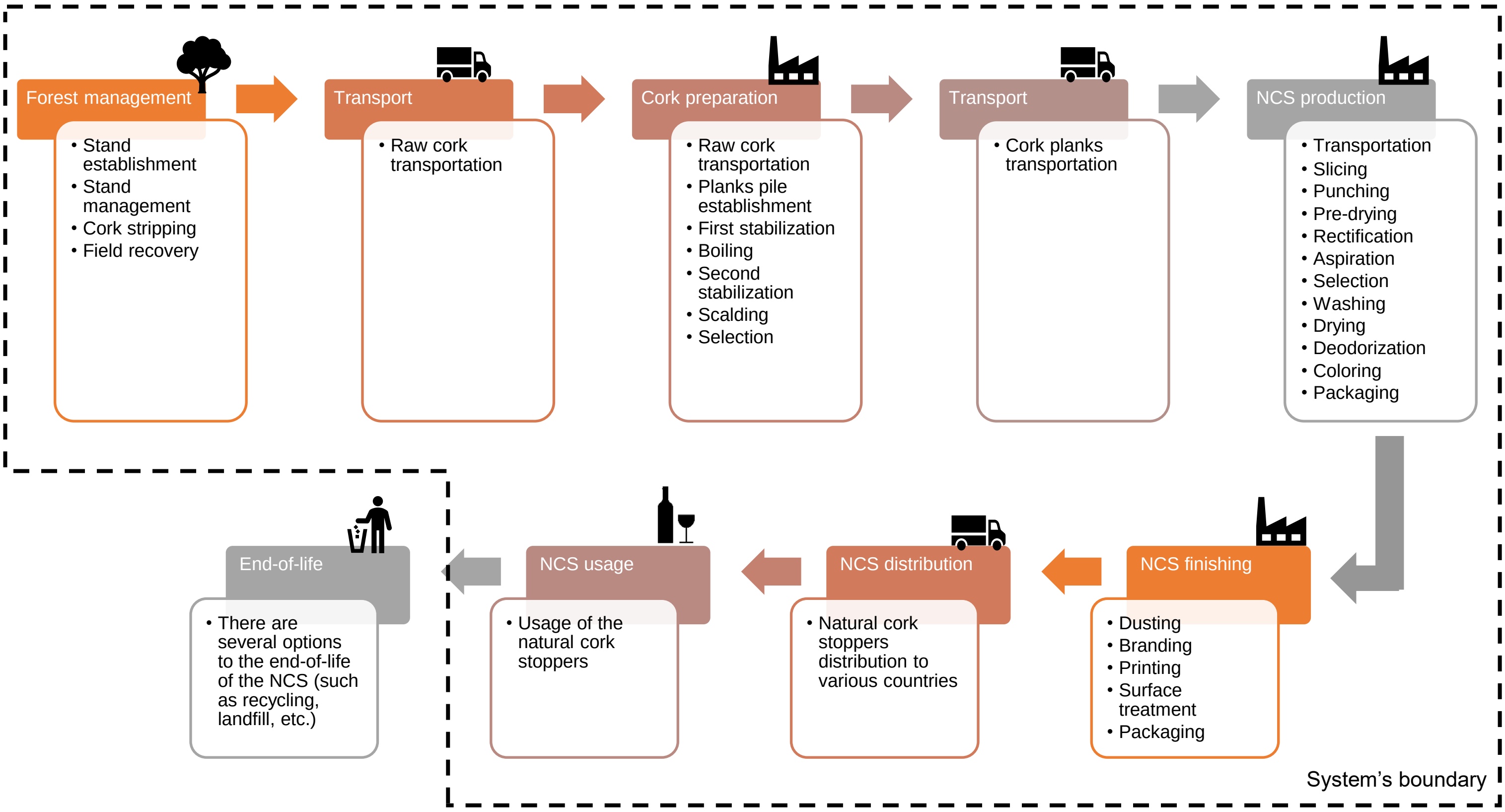

Figure 14 - NCS's Life cycle and boundary

The life cycle of a natural cork stopper is, in the present study, considered to be invariable, meaning that the processes do not change even if the entity producing it, is changing. Said that, the life cycle described in the present section is analogous to the life cycle presented by Demertzi, Silva, et al. (2016) and the description of the processes is also corroborated by the information gathered in APCOR (2015).

The first process of natural cork stoppers' life cycle is the **forest management**. This process includes the stand establishment (includes cut-over clearing, ripping, planting, fertilization and dead plants substitution), stand management (includes spontaneous vegetation cleaning, pruning and thinning), manual cork stripping and the field recovery (the cork oak at the end of its life is cut – its lifespan is approximately 170 years). The forest management process takes place in Portugal, Spain, Morocco, Algeria and Tunisia. The assumptions regarding the forests locations is explained in detail in Appendix B (Figure 37 shows the life cycle processes locations; then Table 17 and Table 18 show the assumptions made to get to the forest locations).

Then, the next process in the life cycle is the **cork preparation**. The first task included in this process is the transport of the raw cork from the forest areas to the cork preparation units. Then, the cork slabs are manually put together into piles at the cork preparation unit. The first stabilization is the process that follows the cork piles establishment: the cork piles are left at open-air for about six months until they achieve the required moisture content of 6 to 10%. After the planks rest for around six months, they are boiled. This boiling period lasts at least one hour, and its objectives are to clean the cork, to extract water-soluble substances, to increase the thickness (reduce the density) and lastly, to make the cork softer and more elastic. Besides that, during the boiling process, the cork planks increase its volume in about 20%. The second stabilization period comes after the boiling process. This period last for two to three weeks. This stabilization allows the planks to rest and helps them to flatten. Besides that, this second stabilization also allows the cork planks to reach the ideal moisture content for processing (14%). Once the planks are flat and rested for that period of time, they are ready to move to the scalding process – a process similar to boiling (hence, also known as the second boiling). The scalding occurs for approximately 30 minutes. Then, the manual selection takes places – the planks are separated into quality categories (based on their thickness, porosity, and appearance) and then the ones with the appropriate characteristics are selected to continue with the production process. The planks that do not gather the appropriate characteristics to be transformed into cork stoppers, are sent to the agglomeration production (for the Floor & Wall Coverings, Composite Cork, and Insulation Cork BUs). The cork preparation stage occurs in the same places where the forests are (Portugal, Spain, Morocco, Algeria and Tunisia). The assumptions made to get to get to those locations (and respective references) are clarified in Appendix B (Tables 19 and 20).

Once the cork planks are ready to be processed, they are transported to the production and finishing units (in Portugal). There it starts the **production** process. The first activity of the production process is the slicing – here, the cork planks are cut into strips. The next action in this process is punching: the perforation of the cork strips with a drill in order to obtain a cylindrical stopper. Also here, the waste obtained through this process is used for cork granulate (this granulate can go to the technical stoppers production, to the Floor & Wall Coverings BU, the Composite Cork BU, etc.). After obtaining the cylindrical form of the cork stoppers, the pre-drying process takes places – the cylinders go inside a kiln to lower their humidity content to around 11%). Next, the rectification is performed. This rectification aims to obtain the final dimensions desired and to regularize the surface of the NCS. After the rectification, the aspiration is performed to remove the cork dust. Similar to what happens in the cork preparation stage, also in the production stage there is the need to do a selection - the defective cork stoppers are here eliminated and do not move on in the process. Afterwards, the washing operation uses hydrogen peroxide to disinfect the NCS. Subsequently, the drying process takes place. The NCS enter a kiln in order to lower the humidity content down to 6%. This moisture content ensures an optimal sealing performance and also reduces microbiological contamination. Then the deodorization action (using water vapor and ethanol) cleans the stoppers surface. Later on, the cork stoppers are colored. The coloring is performed with the use of waterborne coating. Finally, the last step in the production stage is the packaging. The natural cork stoppers are stored in plastic bags of 500 to 1000 stoppers. The production process occurs in Portugal and the respective address, assumptions made, and references are in Appendix B (Table 21).

The next process in the life cycle of the natural cork stoppers is the **finishing**. This process includes five operations: dusting, branding, printing, surface treatment and packaging. Since the facilities where the production is performed are the same as the finishing ones, there is no need for transportation (the assumptions are once again explained in Appendix B) . So, the output from the production process – the unfinished natural cork stoppers – are the main input in the finishing stage. Said that, the unfinished natural cork stoppers enter the stage of finishing which starts with the dusting process (removal of dust). Then, using a heated metallic surface, the stoppers pass through a process of branding; and after, though a process of printing with food quality ink. The last detail before packing the NCS is the surface treatment, which ensures an easier insertion and extraction of the stoppers in the bottles. Lastly, the cork stoppers are packed in waterproof bags, containing sulphur dioxide (SO_2) to avoid contamination – the SO_2 blocks microbiological proliferation. The output of the finishing stage is the (finished) natural cork stoppers.

The next process included in the system's boundary is the NCS **distribution**. This process represents the transportation/distribution to the finished natural cork stoppers to the bottling centers around the world that are clients of Corticeira Amorim. The locations to where the NCS are transported to are: Portugal, France, Spain, Italy, Germany, USA, Australia, South Africa, Chile, Argentina, China, Bulgaria, Hungary, Moldavia and Austria. The assumptions made to get to this final destinations are explained in Table 22 of Appendix B.

The last process contained within the system boundary is the NCS **usage**. It is important to note that the use of natural cork stoppers does not have any environmental impact associated with it. For that reason, this stage of the life cycle was not modelled in SimaPro. Besides that, there is no transportation between the NCS distribution process and the NCS usage one, because they were considered to take place in the same locations (Portugal, France, Spain, Italy, Germany, USA, Australia, South Africa, Chile, Argentina, China, Bulgaria, Hungary, Moldavia and Austria).

The last process of the life cycle is the **end-of-life**, which is not included in the chosen boundary. The NCS can have several ending such as recycling, landfill, reuse, etc.

5.1.2.2 Step 2.2 - Inventory analysis (LCI)

The LCI is based on the one developed by Demertzi et al. (2016). The main differences rely on the transport operations, since these depend on the supply chain entities' locations (suppliers, customers, factories, etc). Table 4 presents the inventory data (inputs and outputs) necessary in the processes of cork preparation. The transport from the forest to the cork preparation facilities is included in the LCI of the cork preparation stage, and the flows are listed in Table 4.

Table 4 - Inventory data per functional unit (cork preparation) (Demertzi et al. (2016))

Inputs/outputs	Quantity	Unit
	Inputs:	
Raw cork[11]	140.834,4	kg
Electricity	7.267,761	kWh
Natural gas	6.652,314	m^3
Water	676,0053	m^3
Transport - Truck (Europa)	7.794,481	tkm
Transport - Truck (ROW)[12]	1.019,641	tkm
Transport - ship	26,05437	tkm
	Outputs:	
Cork planks	98.584,1	kg
Cork residues	42.250,33	kg
Sludge	3.443,402	kg
Wastewater	654,8801	m^3

The inventory of the other processes of the NCS life cycle are displayed in Appendix B (Table 24 to 26). The SimaPro references of all processes is also presented in Appendix B (Tables 27 to 31).

5.1.2.3 Step 2.3 – Impact assessment (LCIA)

This step was performed using the SimaPro software and the methods used were the ReCiPe 2016 (Hierarchist) with a mid- and endpoint level analysis, and the IMPACT 2002+ to double-check and confirm the results obtained with ReCiPe. The SimaPro is the chosen software since it is the most used one in the literature reviewed (in Chapter 3.1). ReCiPe is the chosen method because it is also one of the most used methods in the literature analysed and it is recommended by the United Nations (Santos et al., 2019). The Hierarchist model of ReCiPe is the most commonly used one in scientific studies and it is considered to be the default model, so it is often described as the consensus model, that is why this was the chosen model (PRé Sustainability, 2012). The IMPACT 2002+ was the second method chosen to confirm the results, because it is also an impact with mid- and endpoint levels.

The 17 midpoint categories (or impact categories) of ReCiPe are: global warming (GW), stratospheric ozone depletion (SOD), ionizing radiation (IR), ozone formation (OF), fine particulate matter formation (FPMF), human carcinogenic toxicity (HCT), human non-carcinogenic toxicity (HNCT), water consumption (WC), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TEco), freshwater ecotoxicity (FEco), marine ecotoxicity (MEco), land use (LU), mineral resources scarcity (MRS), fossil resources scarcity (FRS). ReCiPe's three endpoint categories are: human health (HH), ecosystems (ECO) and resources (R). The normalization and weighing factors of the endpoint categories and the midpoint factors are displayed in Table 14 of Appendix A and Figure 36 (also in Appendix A) represents the relationship between the midpoint categories and endpoint

[11] Raw cork accommodates all the environmental impact associated with the forest management stage. When inserting the raw cork in SimaPro, the software assumes the impacts associated with the processes prior to getting to that stage – all the processes included before getting the raw cork stripped and ready to use.
[12] ROW = Rest of the World

categories. Regarding the IMPACT 2002+, its 15 midpoint categories are: carcinogens (C), non-carcinogens (NC), respiratory inorganics (RI), ionizing radiation (IR2), ozone layer depletion (OLD), respiratory organics (RO), aquatic ecotoxicity (AEco), terrestrial ecotoxicity (TEco2), terrestrial acidification (TA2), land occupation (LO), aquatic acidification (AA), aquatic eutrophication (AE), global warming (GW2), non-renewable energy (NRE) and mineral extraction (ME2); and its four endpoint categories are: human health (HH2), ecosystems quality (EQ), climate change (CC) and resources (R2).

5.1.2.4 Step 2.4 – Interpretation

The interpretation step aims to analyse all the outputs generated along the E-LCA application. The first output generated in the LCIA step are the characterized values of the midpoint categories. Consequently, these are the values that have the least level of uncertainty associated with. For that reason, these values deserve to be analysed in detail. The characterized values obtained using the ReCiPe method are shown in Table 5.

Table 5 - Characterized values per impact category (NCS - E-LCA)

Impact category	Characterized value	Unit
GW	56308,019	kg CO2 eq
SOD	0,17793568	kg CFC11 eq
IR	330,71089	kBq Co-60 eq
OF	515,77321	kg NOx eq
FPMF	84,65925	kg PM2.5 eq
TA	229,03125	kg SO2 eq
FE	2,8969237	kg P eq
ME	9,7259522	kg N eq
TEco	232579,63	kg 1,4-DCB
FEco	78,037922	kg 1,4-DCB
MEco	256,02601	kg 1,4-DCB
HCT	423,02995	kg 1,4-DCB
HNCT	10617,133	kg 1,4-DCB
LU	667806,2	m2a crop eq
MRS	83,292909	kg Cu eq
FRS	27709,848	kg oil eq
WC	1377,0361	m3

The characterized values have different units from category to category, which means that they cannot be compared. However, these values can be divided in terms of the contribution of each process to the impact categories. In order to analyse the contribution of the processes to these midpoint categories, first, the most relevant categories need to be found. An efficient way to discover which are the most impactful categories, is by applying the Pareto analysis to the normalization values of the midpoint categories because these values are dimensionless, and consequently, can be compared. Figure 15 presents the application of the Pareto analysis to the normalized results obtained using the ReCiPe method. As one can observe in Figure 15, the Pareto Rule (also known as the 80/20 rule) is valid for the present case, around 20% of the midpoint categories (20% of 17 categories is 3,4 – so around 3 or 4 categories) are responsible for about 80% of the environmental impacts.

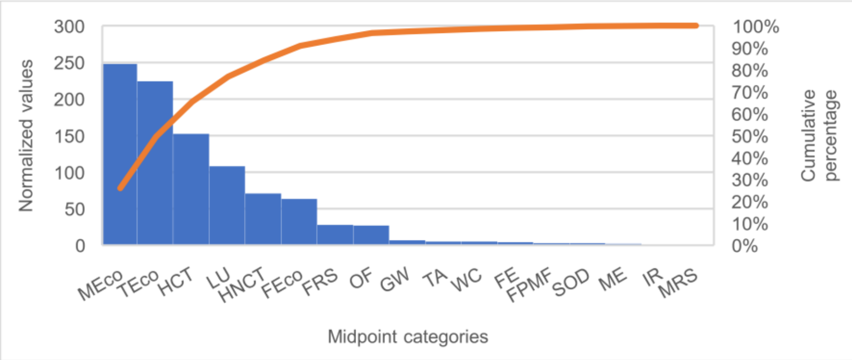

Figure 15 - Pareto analysis (midpoint categories) using ReCiPe – NCS (E-LCA)

The midpoint categories in Figure 15 are ordered from the most impactful (with higher normalized value) to the least impactful (with smaller normalized value). The orange line shows the cumulative values of the environmental impacts of each of the midpoint categories and on the right side of the graphic one can observe that when crossing the 80% value with the orange line, the result is approximately aligned with the fourth category (corresponding to the LU category – the fourth most impactful category in this CS). Accordingly, the four first categories - marine ecotoxicity, terrestrial ecotoxicity, human carcinogenic toxicity and land use – are responsible for about 80% of the total environmental impacts. Marine ecotoxicity is a category that describes the impacts of the emissions to air, water and soil of toxic substances on marine ecosystems, in other words, the effects of metals in the oceans (Ministry for the Environment Manatú Mo Te Taiao, 2020). These toxic substances mentioned are mainly emissions of heavy metals and sulphuric acid (Borrion, Khraisheh, & Benyahia, 2012). Terrestrial ecotoxicity also represents the impacts of toxic substances emissions but on terrestrial ecosystems (Ministry for the Environment Manatú Mo Te Taiao, 2020). Human carcinogenic toxicity represents the emissions (of carcinogenic substances) that occur now but only have impact in the future (Goedkoop et al., 2013). Lastly, the land use category, refers to the damage caused to the ecosystems by the land occupation and transformation (Goedkoop et al., 2013). One of the most relevant components of this category are the CO_2 emissions due to land transformation.

In order to double check the information regarding the midpoint categories, a second method is useful. So, for that reason, Figure 16 shows the results obtained when applying the Pareto Rule to the IMPACT 2002+ midpoint categories.

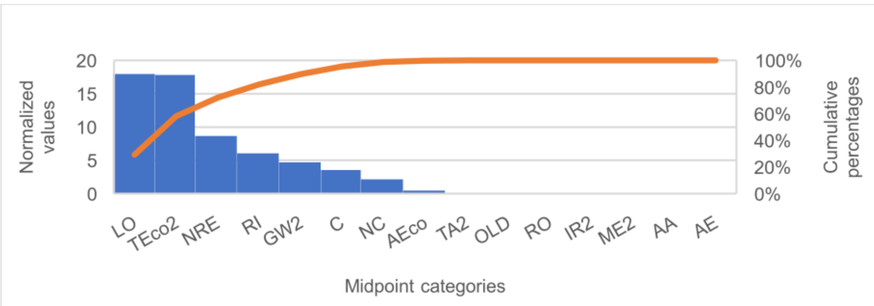

Figure 16 - Pareto analysis (midpoint categories) – NCS using IMPACT 2002+ (E-LCA)

Figure 16 shows that, according to the IMPACT 2002+ method, the most concerning impact category is the land occupation. The land occupation category here is the equivalent of the land use to the ReCiPe method, which is also included in the top 20% categories that gather 80% of the environmental impacts. Then, Figure 16 shows that the second most worrying category is the terrestrial ecotoxicity, which also occupies the second ranking place in the ReCiPe analysis. The non-renewable energy and the respiratory inorganics are considered here as two of the most concerning impact categories as well. The non-renewable energy category of IMPACT 2002+ method is similar to the fossil resources scarcity (FRS) of ReCiPe (which occupies the seventh place in the ranking of most worrying impact categories, according to that method). Similarly, the respiratory inorganics is the equivalent to the fine particulate matter formation (FPFM) of ReCiPe. However, this last category (FPFM) occupied the thirteenth place in the ranking of most concerning categories, according to the ReCiPe method.

Now, one is ready to go back to the characterized values and analyse them in a more efficient way, since the Pareto Rule enabled to understand which categories are responsible for 80% of the environmental impacts. Figure 17 shows the contribution of each process of NCS's life cycle to the characterized values of MEco, TEco, HCT and LU categories. These contributions were determined using the ReCiPe method.

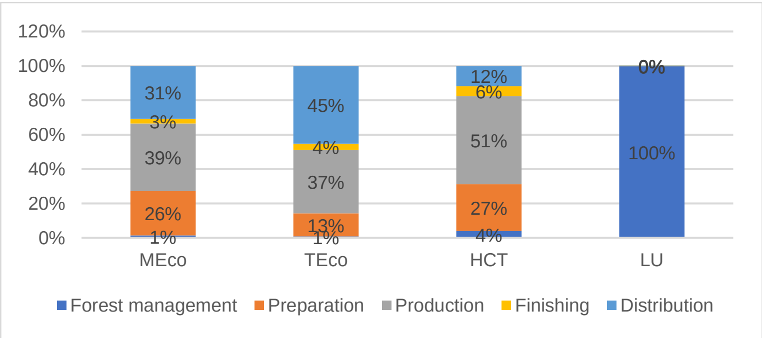

Figure 17 - Contribution of each process to the characterized values of the most relevant categories – NCS (E-LCA)

The process that contributes the most to the **marine ecotoxicity** is production (39%), followed by distribution (31%) and preparation (26%). The other two processes are accountable for a relatively smaller percentage of this category impacts. When looking in more detail to the first mentioned process (the production), one finds out that the biggest contributor to this process is the truck transportation (ROW), with a percentage of 38%. An alternative to the truck transportation is the train. A comparative analysis of 1 tkm transport by truck and by train was performed in SimaPro and confirmed that the train transportation is less harmful to the environment (regarding the marine ecotoxicity category, 1tkm of truck transportation has a characterized value of 0,001545 kg 1,4-DCB and the train transportation has 0,000105 kg 1,4-DCB; so, if it would be opted by a train transportation, there would be a significant decrease of the marine ecotoxicity impacts). Figure 18 shows the rail freight corridors between Portugal and Spain and Figure 19 shows the rail freight corridors in North Africa.

Figure 18 - Rail freight corridors (part of Europe) (RNE, 2020)

Figure 19 - Rail freight corridors (North Africa) (African Development Bank, 2015)

The cork planks that are prepared in the Spanish cork preparation facility (in Girona) need to be transported to Coruche, Portugal (where is located the production plant), and this transaction implies a high number of tonne-kilometres. Hence, this transportation is currently being operated by truck freight and can be adjusted to be performed by a combination of train and truck (Scenario 1). According to Figure 18, the best route to take is from Barcelona to Lisbon (and the remaining route by truck). The overall distance to travel by truck is 180 km (around 100 km from Girona to Barcelona plus 80 km from Lisbon to Coruche). The total distance travelled by train is around 1007 km (from Barcelona to Lisbon (Railcc, 2020)). So, with these alterations performed, the marine ecotoxicity characterized value of the production process decreases from 170,10 kg 1,4-DCB to 158,80 kg 1,4-DCB (a decrease of about 7%). Also in this process' score there is a reduction. The production process with only truck transportation (from Girona to Coruche) has a score of 4,62 kPt, while the integration of the train transportation reduces the score to 4,59 kPt. If one opts for integrating the rail mode also in the African part of the life cycle (Scenario 2), the results can be even better. So, if the company opts by using a combination of train and truck transportation in both Spain and North of Africa (using the roots shown in Figures 18 and 19), the production process score in the marine ecotoxicity category decreases from 170,10 kg 1,4-DCB to 153,16 kg 1,4-DCB (a decrease of around 10%). The process score also decreases to 4,58 kPt, a lower score than both of the other two options. Table 39 of Appendix C shows all the decreases (in percentage) of all impact categories when comparing the baseline scenario with Scenarios 1 and 2.

The second input that contributes the most to the production process is the natural gas (29%). Some alternatives to this input could be the solar energy or the wind energy. When comparing 1kWh of these three types of energy in SimaPro, the conclusions regarding the MEco category are that the wind energy is the best one (0,000109 kg 1,4-DCB), then the solar energy (0,000123 kg 1,4-DCB) and lastly, the natural gas (0,000344 kg 1,4-DCB). However, when looking to their SS, the ranking is different. The best option is still the wind energy, with a SS of 0,688625 mPt, then the natural gas with 1,195456 mPt and in the last position is the solar energy with a SS of 1,698181 mPt. So, out of the two alternatives proposed, it became clear that the best option is the wind energy. When implementing the wind energy in the production process instead of the natural gas, the MEco value decreases from 170,10 kg 1,4-DCB to 151,19 kg 1,4-DCB (a decrease of 11%). If the company decides to take both suggestions and changes the natural gas to wind energy and also combines the truck and train modes instead of just using truck, the characterized value of MEco category decreases around 21% (to 134,25 kg 1,4-DCB). The overall score of the production process also decreases. In the scenario of changing just the natural gas to wind energy, the score goes from 4,62 kPt to 4,59 kPt, while the scenario of changing both inputs (truck transport and natural gas) represents an even smaller score of 4,54 kPt.

Then, the cork waste represents about 12% of the production process impacts to the MEco category. The cork waste can be introduced in the production process of other products of Corticeira Amorim, not in the natural cork stoppers because its base are the cork planks.

The second most relevant impact category, according to the Pareto analysis, is the **terrestrial ecotoxicity** category. Regarding the processes of the NCS's life cycle, the one impacting the most this category is the <u>distribution</u> (45%) followed by <u>production</u> (37%), and <u>preparation</u> (13%). Lastly, the two other processes have a small contribution to this category. Taking the most impactful process to this category – the <u>distribution</u> -, its analysis reveals that the majority of the impacts come from the truck transportation in Europe (around 62%). Then, the second input that contributes the most to the distribution process impacts on the TEco category is the truck transportation in the rest of the World (about 38%). The other input of the distribution process – the sea transportation -, has an impact of approximately 0%. So, in order to reduce the impacts of the TEco category, the most efficient way to do so is by using alternatives to the truck transportation (both inside and outside Europe) in the distribution stage. Here, once again, the alternative lies on toggling between the truck and train modes. The comparison performed in SimaPro between 1 tkm of truck transportation and 1 tkm of train transportation showed that the train transportation has a TEco characterized value of 0,107844 kg 1,4-DCB, which is a much smaller value than the truck option with 2,174264 kg 1,4-DCB (a 95% decrease). These numbers show that the terrestrial ecotoxicity category benefits a lot from the rail option. So, out of the 15 final distribution locations, it was considered the most relevant ones in terms of quantity distributed and distance travelled (the locations that have a share of NCS distribution higher than 5%, that require travelling distance higher than 500 km, and that are located in Europe, since it that is the main contributor). The distribution locations that fit these criteria are: France, Spain, Italy and Germany (the percentages of NCS distributed and travel distances are explicit in Appendix B, Table 22). The proposed alternative is to alternate between the railway and the road transportation, using the rail freight corridors. So, when implementing these alterations and comparing in SimaPro the distribution process with and without rail freight, one can conclude that the option with train reduces the terrestrial ecotoxicity impacts (of this process) in about 20%. The distribution process before any alterations had a characterized value in this category of 232579,63 kg 1,4-DCB and it decreased to 184908,09 kg 1,4-DCB. The improvement is also noticeable in the process' score. Before, the distribution process had a score of about 5,38 kPt, and it got reduced to 5,29 kPt (a reduction of around 1,6%).

Once again, by looking to the Pareto Rule applied to the normalized values of the impact categories, the third most relevant category is the **human carcinogenic toxicity**. In terms of this category characterization, Figure 17 shows that the one process that impacts the most this category is the production process (51%), followed by preparation (27%), and distribution (12%). The other two processes (forest management and finishing) are not so relevant. So, if the goal is to reduce the HCT impacts, it is important to look to the process that has the biggest impact – the production process. Inside this process, the input that has the highest contribution (around 44%) is the hydrogen peroxide. The H_2O_2 is part of the washing procedure and it is required to disinfect the NCSs. Demertzi, Silva, et al. (2016) explains that this chemical (along with others used in the washing process, such as the sodium hydroxide, the sodium bisulphate and the enzymes) cannot be altered because they are required in specific amounts in order to ensure the quality of the natural cork stoppers. The second most impactful element is the cork waste (28% of the production process impacts on the HCT category). As previously mentioned, the best solution is to adopt a circular economy by reintroducing the cork waste in the production of other products such as granulated, agglomerate and cork composite. The third element inside the production process that impacts the most the HCT category is the truck transportation. The alternative is to combine the rail and road modes. The options explored in the MEco case (also for the production process) were to change the transportation mode in Spain first and then to change it also in Africa. In the HCT case, when comparing 1 tkm of truck transportation with 1 tkm of train transportation, the results are better in the latter scenario. The first mentioned mode presents a value of 0,000943 kg 1,4-DCB and the second one a value of 0,000888 kg 1,4-DCB, which represents a decrease of only 0,003%. However, the train mode is still more favorable than the truck. So, after applying the same changes as the one mentioned in the MEco's case, it was possible to ascertain that when changing only the transportation from Spain, the HCT results decrease around 0,2%. However, if the company changes the transportation mode also in Africa, the results of the HCT category increase 0,14%. So, if the goal is to reduce the HCT impacts, it is better to only use train mode for the cork planks coming from Spain. The reason for the higher results in the second scenario (adding the transport of the African cork planks) is because the overall distance travelled is superior if one takes the train and truck[13]. In conclusion, the best solution in this case is to just use the train in Spain.

Lastly, the category that is left is the **land use**. By analyzing this category's characterized values (see Figure 17), it is possible to conclude that almost 100% of the impacts are assigned to the forest management process. Inside this process, the raw cork is accountable for about 99,95% of the land use impacts, and the sawing activity is responsible for the rest (0,05%). Something that can be studied regarding the raw cork is its usage optimization. Meaning that the goal should be to utilize the maximum percentage of raw cork that goes into process, to reduce the waste. In the specific case of the land use category, it would also be useful to analyse the map of the cork oak forests and study if the layout is optimized or if the land in use is bigger than what is actually needed. So, the study of the land optimization and raw cork usage optimization in the production

[13] When using just the truck, the total distance travelled in Africa is 8800 km, while when using the truck and the train in Africa, the overall distance travelled is 11337 km. This happens because in North Africa the railways are more limited and there is the need to travel more to get to the train stations.

processes are the two main suggestions gave here. This study is not performed here, because it would require a deeper analysis and more data would be necessary, such data that is not publicly available and is site specific.

5.1.3 Step 3 - S-LCA application

This subsection consists of the S-LCA application (Step 3 in the methodology) to the production of **natural cork stoppers** by Corticeira Amorim case study. It consists of the application of S-LCA methodology to the CS and its four inherent sub-steps (Step 3.1 to 3.4), corresponding to subsections 5.1.3.1 to 5.1.3.4, respectively.

5.1.3.1 Step 3.1 - Goal and scope definition

Goal: The main goals are to learn about the social impacts of the natural cork stoppers (NCS), to compare the NCS life cycle with the pellets and to formulate conclusions about the social impacts of the forest sector.

Scope:

Product characteristics: The product studied here is the same as the one in the E-LCA study (Subsection 5.1.2), so its characteristics are exactly the same as described in the mentioned section.

Functional Unit: The quantity of product necessary to generate a revenue of 100.000 € per year.

Activity variable: Hours of work.

Boundary: The boundary is the same as used in Subsection 5.1.2 for the E-LCA study.

Life cycle: Also the life cycle of the NCS is the same as the one explained in Subsection 5.1.2.

5.1.3.2 Step 3.2 – Inventory analysis (LCI)

The LCI step of the S-LCA, as said in Chapter 4 (Research Methodology), consists of gathering the inventory of each stage of the NCS's life cycle translated into price (in USD 2011), GTAP sector and country of origin. Table 6 is the LCI of the cork preparation stage in Portugal for the S-LCA study. The process to get to those final values (illustrated in Table 6) is not straightforward. So, in order to understand the procedure of how to get to these values, the explanation is in Appendix D, which is divided into three parts. The best way to read the information in Appendix D is by first understanding the path taken to get to the final values in Table 6 (and likewise to Tables 81 to 87 of Appendix D and then to the pellets S-LCA as well); and this path can be divided into three steps:

1. **Research of the countries of origin (only imports):** The first step taken was the research of the countries of origin of each input of the inventory (material, energy, water, etc.) and respective percentage of imports. This information of the countries of origin (of

the imported part) was collected from the Atlas of Economic Complexity (Growth Lab of Harvard University, 2020).

2. **Prices research:** Secondly, the prices of each inventory input were collected. The necessary explanation and reference from where the prices were taken are all in Appendix B.
3. **Research of the domestic production percentage:** Lastly, the percentage of domestic production of each inventory input was searched. This is the part of the inventory input that is produced in the country where the life cycle stage is taking place. These percentages, respective references and relevant notes regarding the logic behind getting to the final percentage are all discriminated in Appendix B.

Therefore, the Tables 42, 55 and 68 of Appendix D explain the calculations to get to the final values displayed in Table 6, and all the references.

*Table 6 - LCI of the **cork preparation** stage in **Portugal**, for Corticeira Amorim*

Material	Price (USD 2011)	GTAP Sector Code	Country of origin[14]	Country percentage[15]
Raw cork	1,891042 USD2011 per kg	FRS	Portugal	53,61%
			Spain	29,98%
			Italy	13,73%
			USA	2,02%
Electricity	0,156241 USD2011 per kWh	ELY	Portugal	83%
			Spain	17%
Natural gas	0,060358 USD2011 per kWh	GAS	Spain	100%
Water	1,667826 USD2011 per m^3	WTR	Portugal	100%
Road transport (diesel)	1,257963 USD2011 per L	OTP	Spain	48,2%
			Russia	11,41%
			Belgium	11,26%
			Netherlands	9,04%
			China	3,97%
			Saudi Arabia	3,64%
			France	2,24%
			Italy	1,74%
			Egypt	1,49%
			Brazil	1,34%

The LCI of the other processes of the NCS life cycle are in Tables 81 to 87 of Appendix D. The references and calculations to get to the final results of the inventory list are displayed in Tables 43 to 76 (Appendix D).

5.1.3.3 Step 3.3 – Impact assessment (LCIA)

The software chosen is the same as in the E-LCA – SimaPro – because this software provides the databases necessary to assess this S-LCA. The method selected to perform this LCIA step

[14] The countries from where the materials are imported and respective percentages were all taken from the Atlas of Economic Complexity (Growth Lab of Harvard University, 2020).
[15] If the percentage is lower than 0,05%, then it does not appear in the present table (Table 6) and the respective country will not be included in the calculations. The same is valid for all the similar tables (Table 81 to 87 of Appendix D).

is Social Hotspot 2019 Subcategories & Categories Method with Damages. This choice was based on the recommendation made by the Pré (Pré Sustainability B.V., 2020).

The method has five (endpoint) categories: Labour Rights & Decent Work (LRDW), Health & Safety (HS), Human Rights (HR), Governance (G) and Community (Cm). These categories are subdivided into subcategories (also known as midpoint categories or themes). Table 15 of Appendix A contains the endpoint categories, the respective midpoint categories (and respective issues) and the weights of each midpoint category. The midpoint categories belonging to the **Labour Rights & Decent Work** category are: Wage (W), Poverty (P), Child Labour (CL), Forced Labour (FL), Excessive Working Time (EWT), Freedom of Association, Collective Bargaining, and Right to Strike (FoA), Migrant Labour (ML), Social Benefits (SB), Labour Laws & Conventions (LLC), Discrimination (D) and Unemployment (U). Then, the themes considered in the **Health & Safety** category are: Occupational Toxics & Hazards (OTH) and Injuries & Fatalities (IF). The **Human Rights** categories divides into: Indigenous Rights (IRi), Gender Equity (GE), High Conflict Zones (HCZ), Non-Communicable Diseases and other health risks (NCD) and Communicable Diseases (CD). **Governance** one has two themes: Legal System (LS) and Corruption (Cr). Lastly, the themes of **Community**: Access to Drinking Water (ADW), Access to Sanitation (AS), Children out of School (CoS) Access to Hospital Beds (AHB) and Smallholder vs. Commercial Farms (SCF).

5.1.3.4 Step 3.4 – Interpretation

The characterized values are the first output that the software gives, and they are displayed in Table 7.

Table 7 - Characterized values per impact category (NCS - S-LCA)

Impact category	Unit	Total
1A Wage	1A mrheq	57323,69
1B Poverty	1B mrheq	82931,46
1D Child Labor	1D mrheq	79463,46
1E Forced Labor	1E mrheq	106525,1
1F Excessive WkTime	1F mrheq	53141,42
1G Freedom of Assoc	1G mrheq	158942,8
1H Migrant Labor	1H mrheq	203657,6
1I Social Benefits	1I mrheq	38111,04
1J Labor Laws/Convs	1J mrheq	21219,87
1K Discrimination	1K mrheq	106744,2
1L Unemployment	1L mrheq	58913,33
2A Occ Tox & Haz	2A mrheq	121248,1
2B Injuries & Fatalities	2B mrheq	135900,9
3A Indigenous Rights	3A mrheq	42615,07
3B Gender Equity	3B mrheq	71074,22
3C High Conflict Zones	3C mrheq	112315,8
3D Non-Communicable Diseases	3D mrheq	23597,01
3E Communicable Diseases	3E mrheq	43394,33
4A Legal System	4A mrheq	72384,94
4B Corruption	4B mrheq	106343,9
5A Access to Drinking Water	5A mrheq	52021,87
5B Access to Sanitation	5B mrheq	52755,04
5C Children out of School	5C mrheq	88630,38
5D Access to Hospital Beds	5D mrheq	96957,16
5E Smallholder v Commercial Farms	5E mrheq	105593,4

These values alone do not mean much from the perspective of an analysis. However, when they are disassembled into the processes contributions, it becomes easier to analyse it. Similar to what was done in the environmental analysis, one will find the most relevant impact categories. Figure 20 shows the Pareto analysis applied to the normalized values of the impact categories.

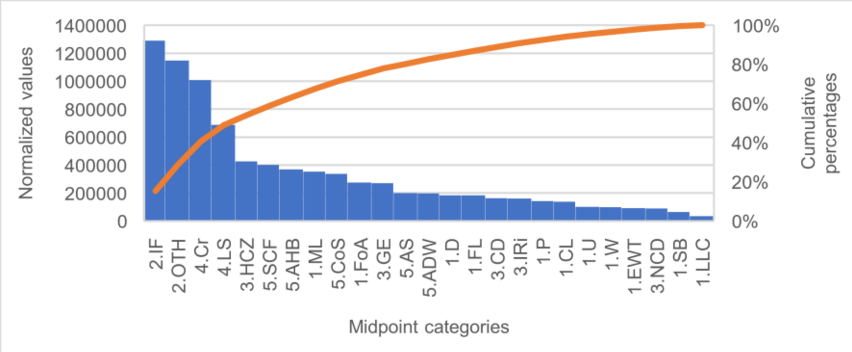

Figure 20 - Pareto analysis (midpoint categories) – NCS (S-LCA)

From Figure 20 it is possible to conclude that the categories responsible for 80% of the overall social impacts are, from most to least impactful: IF, OTH, Cr, LS, HCZ, SCF, AHB, ML, CoS, FoA, GE, and lastly, AS. The category Injuries & Fatalities represents the occupational injuries that result from accidents that occur at work and that may result in death, personal injury, or a disease that involves loss of work time (ILO, 2020; Norris et al., 2016). Then, the Occupational Toxics & Hazards category represents the damage that hazardous and toxic substances (chemicals that have the capacity to harm living organisms) can have in the workers' health (Norris et al., 2016). The Corruption category assesses the country's risk of corruption, which can include activities like bribery, extortion, cronyism, bias, patronage, and embezzlement (Norris et al., 2016). The Legal System category evaluates factors such as if a country's population is able to obey the society rules, and also how impartial are the judiciary decisions (if they are or no influenced by other power forces) (Norris et al., 2016). The High Conflict Zones category evaluates the nation's potential to have conflicts (either societal (civil, ethnic and communal) or interstate warfare) (Norris et al., 2016). The Smallholder vs. Commercial Farms category compares the smallholder farmers (the ones with limited resources) with the commercials farmers (the ones that have a bigger dimension and can take advantage of economies of scale or other growth techniques). The smallholders often have problems continuing in business because of the commercial farms, since they cannot compete with their prices (Norris et al., 2016). Then, the Access to Hospital Beds category evaluates the country's risk of not having access to hospital beds. The Migrant Labour regards the problems that migrant worker face, such as discrimination (and the severity of this problem depends from country to country) (Norris et al., 2016). The Children out of School category assesses, as its own name indicates, the risk of children not attending school. The Freedom of Association, Collective Bargaining, and Right to Strike category evaluates the country's risk of not having freedom of association, collective bargaining and strike rights (Norris et al., 2016). The category Gender Equity studies the risk of existing gender inequality. Lastly, the Access to Sanitation category studies nation's risk of not having access to improved sanitation (which according to the World Health Organization (2020) is the one that hygienically separates human excreta from human contact).

These categories are now analysed to understand which processes are contributing the most to these impacts. Figure 21 shows the contribution of each process of the NCS life cycle to these categories.

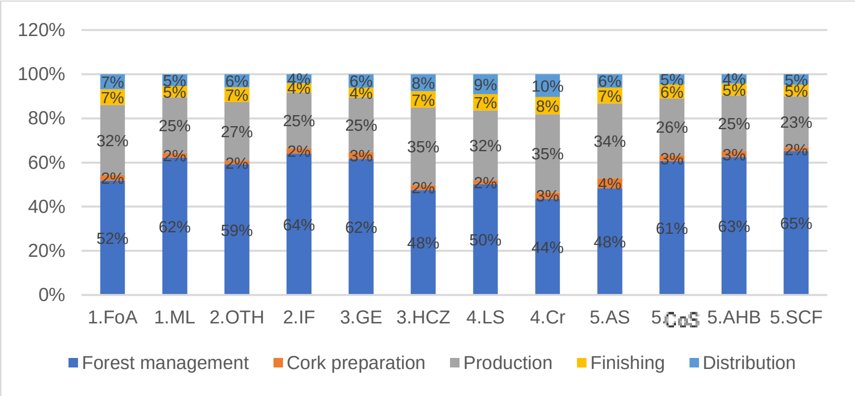

Figure 21 - Contribution of each process to the characterized values of the most relevant categories – NCS (S-LCA)

The most impactful category is the **Injuries & Fatalities** (IF) (see Figure 20). Around 64% of this category's impacts are from forest management, followed by production (25%), finishing (5%), distribution (5%), and preparation (2%). The forest management process is divided in five locations (Portugal, Spain, Morocco, Algeria and Tunisia). Around 68% of the forest management impacts in the IF category correspond to the forest management performed in Portugal. Then, 26% of these impacts are related to the Spanish cork oak forests. The forest management process in Algeria is responsible for around 5% of these impacts, while the Tunisian part of the process gathers 2% and Morocco 0%. At this point, it is relevant to remind that the forest management and cork preparation processes are located in these five locations and the division of work is as follows: Portugal – 72%; Spain – 24%; Tunisia – 2%; Algeria – 1%; and Morocco – 1%. These percentages represent the amount of cork planks that come from each of these locations. So, the forest management activities in Algeria have a higher impact (5%) than the ones in Tunisia (2%), even though Tunisia works with a higher amount of cork. This occurs because the probability of a worker suffering an injury in Algeria is superior of occurring the same in Tunisia. Since the IF is the major social concern of the present life cycle and the forest management process in Portugal is the biggest contributor to this impact, then it would be valuable to reinforce the safety measures in the cork oak forests in Portugal. Some measures that can be adopted are the use of protection uniform by the works, since a lot of the activities performed are manual labour. Besides that, the number of injuries in Algeria need to be managed, since that location has a high value in this category (for the amount of cork managed).

Secondly, the **Occupational Toxics & Hazards** (OTH) category comes next in the ranking of most worrying categories (see Figure 20). The trend in this category is similar to the one of the previous category. The process impacting the most this category is forest management with 59%

of the overall impacts, followed by production (27%), finishing (7%), distribution (6%), and lastly the cork preparation (2%). Looking in detail to the forest management process, around 63% of the process impacts belong to the forest management in Portugal. Then, 20% correspond to the Spanish forest management. In the third position comes the Moroccan forests, with a percentage of around 14%. Lastly, Algeria and Tunisia with 2% and 1%, respectively. The value belonging to the forest management process in Morocco can be considered high when comparing relatively with the amount of cork the first two locations are dealing with. So, this high value of the forest management process in Morocco alerts for possible problems in this country, which require surveillance.

So, since all of the most relevant categories are impacted the most by the forest management process (the range contribution of this process is 44- 65%, see Figure 21), this process will now be under analysis. Also, another trend that is common to all the 12 most worrying categories is the second most impactful process: the production (see Figure 21). This process gathers a range of 23-35% of the categories impacts and it is always the second contributor. Hence, these two processes will be highlighted and studied in more detail.

So, in order not to get repetitive, an individual analysis of the forest management process is performed. Figure 22 shows the contribution of the forest management process per location to the most relevant impact categories.

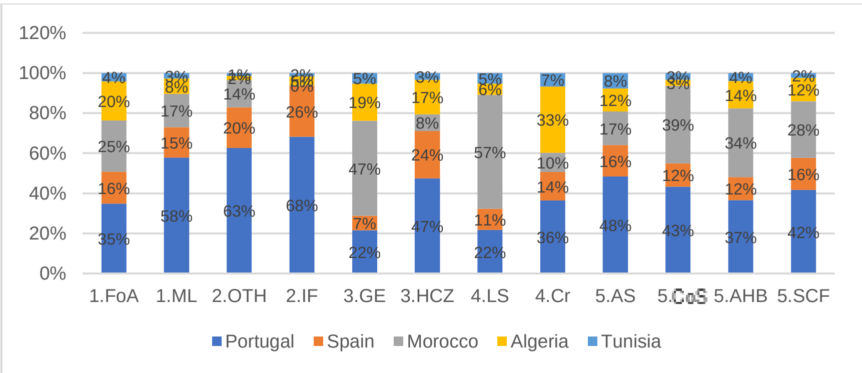

Figure 22 - Contribution of the forest management process (in each location) to the characterized values of the most relevant categories – NCS (S-LCA)

The first two most relevant categories (IF and OTH) were already studied. So, the third most relevant category (the **Corruption** (Cr) - see Figure 20) is dominated by the forest activities in Portugal (36%), and secondly in Algeria (with 33%). So, when it comes to the corruption issue, it is fair to say that Algeria is a problematic location. If Corticeira Amorim wants to reduce the corruption issues associated with the NCS life cycle, the main recommendation would be for the company to elaborate awareness campaigns to their suppliers in this country (addressing topics related to corruption like bribery, extortion, bias, etc.). Besides, Corticeira Amorim, can also demand that their Algerian suppliers have strict policies against corruption.

Regarding the other nine categories left, the Portuguese forests lead in all of them with exception made to Gender Equity and Legal System, where the Moroccan forests lead. The percentage range gathered by the Portuguese location in the forest management process is 35-58%. The lowest percentage corresponds to the Freedom of Association and the highest to the Migrant Labor. The Spanish forests impacts in these categories are between 7-24%, with the highest value corresponding to the High Conflict Zones. The Moroccan forests have percentages of contribution between 17-57%. It is important to highlight the highest value (57%, which belong to the Legal System category) and the Gender Equity where the Moroccan location stands first in the ranking with percentage of 47%. So once again, the Moroccan forests labour have several issues, as one can observe in Figure 22, and the biggest ones are Legal System, Gender Equity, Children out of School, and Access to Hospital Beds. All of the mentioned categories present a percentage higher than 30% when it comes to Morocco. Regarding the forest management process in Algeria, this process contributes from 3 to 20% in the nine categories that were left to analyse. The biggest social problems identified in Algeria (forest management), besides the Corruption already mentioned, are the Freedom of Association (20%) and the Gender Equity (19%). The last location is Tunisia. The contribution of this process location to the overall forest management impacts is significantly small; its contributions are between 2-8%. The biggest social issue in the Tunisia forests is the Access to Sanitation (with 8%). So, the conclusions taken from the individual analysis of the forest management process are that Portugal and Spain show some social problems, but part of their high percentages are caused by their large supply of raw cork; and that Algeria and Morocco (which supply significantly smaller amounts of raw cork) show considerably high impacts in some social categories. Accordingly, the main suggestion would be to reduce the supply of raw cork from Algeria and Morocco and, for example, to move it to Tunisia, which show fewer social problems.

Now, moving on to the second most impactful process – the production. The categories that the production process have the biggest impacts are on the HCZ (35%), the Cr (35%) and the AS (34%) (see Figure 21). A common trend to these three categories arises: the input impacting the most the production stage in these categories is the hydrogen peroxide coming from Spain. In the **HCZ** category, the H_2O_2 from Spain has an impact of 22% in the production process. In this category, the second production input impacting the most is also the H_2O_2 but coming from Israel (7%), which it makes sense since this category is the high conflict zones. Then the water based coverings from Spain contributes 6% to this category, and all the other have a contribution smaller or equal to 5%. Then, inside the **corruption** category, the production input showing the highest value is, as mentioned, the H_2O_2 from Spain (19%). Then, the natural gas from Spain has a contribution of 7% in the corruption category. There are two inputs that show a percentage of 6%, which are the H_2O_2 from Portugal and from Belgium. The other inputs have a contribution smaller or equal to 5%. Lastly, also in the Access to Sanitation category is the H_2O_2 from Spain leading the ranking with a contribution of 22%. The natural gas from Spain has a high contribution to the AS category – 16%. The H_2O_2 from Portugal contributes in 7% to this category and the same product from Belgium has a contribution of 6%. Also with 6% is the water based coverings from Spain. Throughout the analysis of the production process, it was possible to understand that

Spain has a strong contribution to the social issues of this process. This conclusion is aligned with the fact that Portugal imports a high number of products from its neighbour country.

5.2 Omnipellets

This section corresponds to Omnipellets CS and is divided into three subsections: 5.2.1 corresponds to Step 1 - Case study contextualization, 5.2.2 is the E-LCA application (Step 2) and 5.2.3 is the S-LCA application (Step 3). The last two sections are divided the same way: 5.2.2.1 and 5.2.3.1 – Goal and scope definition (respectively of the E-LCA and S-LCA – the same applies to the following sub-sections); 5.2.2.2 and 5.2.3.2 – Inventory analysis (LCI); 5.2.2.3 and 5.2.3.3 – Impact assessment (LCIA); and lastly, 5.2.2.4 and 5.2.3.4 – Interpretation.

5.2.1 Step 1 – Case study contextualization

Industry contextualization

Bioenergy is the type of energy that is generated from organic matter (commonly known as biomass). That energy can generate heat, electricity, or gas. The biomass can have origin in plants, agriculture waste, food waste, and others. The present study is only focused on bioenergy that comes from forest waste, since the product under study are the pellets. Pellets are a solid biofuel that is the result of biomass compression (Figure 23 is an illustration of pellets). Pellets have the capacity to produce energy in the form of heat.

Figure 23 – Pellets (MADIPLAC – Madeira e Derivados, 2020)

When talking about the impact that this industry can have in its country (in this case, Portugal), the pellets industry has the potential to reduce the energetic dependency from fossil fuel. The substitution of fossil fuels to pellets will naturally reduce the country's dependence on abroad's energy sources. This implies an obvious reduction in imports and a consequential higher level of self-subsistence. The pellet production also leads to an economic increase in both forest and transport sectors. Besides the added value to the national economy, this activity also helps in forest management and preventing fires (Martos & Cª Lda., 2018b).

The company representing the pellets' CS is Omnipellets, which belongs to Martos & Companhia Lda. The main source of information of this section is Martos & Companhia Lda.'s website.

Mission and Vision

The mission and vision of Martos & Cª Lda., the business group where Omnipellets is integrated, is presented below:

- <u>Mission:</u> "*Our main mission is to be highly committed to growth, satisfaction, and vanguard. These three parameters are the common denominator guiding Martos' activity, inspiring from its most endogenous employees to its most downstream stakeholders to comply with a discipline of excellence and vanguard that allows total customer satisfaction, resulting in* ***sustained*** *and* ***responsible*** *growth*." (Martos & Cª Lda., 2018c).
- <u>Vision:</u> "*To confirm our market position by investing in critical areas to success such as investing in R&D and continuous employee training. Provide* ***welfare*** *to all,* ***sustainably***." (Martos & Cª Lda., 2018e).

Similarly to what happens with Corticeira Amorim, this business group also gives a highlight position to sustainability, by referring it in both their vision and mission. Social and environmental are two of the three pillars of sustainably, the third being economic. When mentioning sustainability, they are consequently giving importance to these three pillars.

Economic dimension is, undoubtfully, an important aspect in all business areas, as their ultimate goal is to have profit. Here, the environmental aspect is also extremely important, since their business strongly relies on the idea of a most sustainable world (they support the forest, use production waste as an energy source, etc.). Lastly, the social pillar is mentioned when referring to their workforce and their stakeholders as a key factor to their success – the continuous employee training is, as mentioned, an essential element of their work.

Business Units

The Martos Group is divided into four business units (Martos & Cª Lda., 2018d):

- **Woods** – The woods business unit is the foundation of all the others, and it feeds their production, once it works as raw material to the other business units of the Martos group;
- **Pallets** – This is the most important business unit since it represents around 40% of its revenue. The Martos group produces two different types of pallets, both made with maritime pine: one with two and other with four entries to the forks of the forklift;
- **Pellets** – Pellets are small cylindrical wood agglomerate made from by-products of the sawmill industry, namely pine chips, and sawdust. Pellets are a 100% natural and renewable biofuel with a high calorific value;
- **Bio-coal** – Bio-coal is a 100% natural and ecological source of energy, produced from woods of forest weed species, such as acacia, mimosa, and others. It is a product designed for home use, cooking traditional grills for consumers who want a natural and healthy product, with high health and wellbeing benefits.

5.2.2 Step 2 – E-LCA application

This subsection consists of the E-LCA application (Step 2 in the methodology) to the production of **pellets** by Omnipellets. It consists of the application of E-LCA methodology to the CS and its four inherent sub-steps (Step 2.1 to 2.4), corresponding to subsections 5.2.2.1 to 5.2.2.4, respectively.

5.2.2.1 Step 2.1 – Goal and scope definition

As already mentioned, the first step of the E-LCA methodology is the goal and scope definition:

Goal: The main goals are to learn about the environmental impacts of the pellets, to compare the pellets life cycle with the NCS and to formulate conclusions about the environmental impacts of the forest sector.

Scope:

Product characteristics (Ferreira, Fernandes, & Nunes, 2015; Omnipellets, 2020):

- Product: Pellets
- Shape: cylindric
- Diameter: 6 mm
- Length: 3,15 to 40 mm
- Density: 600-750 kg/m^3
- Moisture: 10%

Functional Unit: The quantity of product necessary to generate a revenue of 100.000 € per year (which is equivalent to an amount of 434.782,6 kg of pellets – information received via e-mail (Omnipellets, 2020)).

Boundaries: The system's boundary is cradle-to-usage (Figure 24); the time boundary is one year; and the geographical boundary is Portugal.

Life cycle: Figure 24 illustrates the product's life cycle as well as the system boundary.

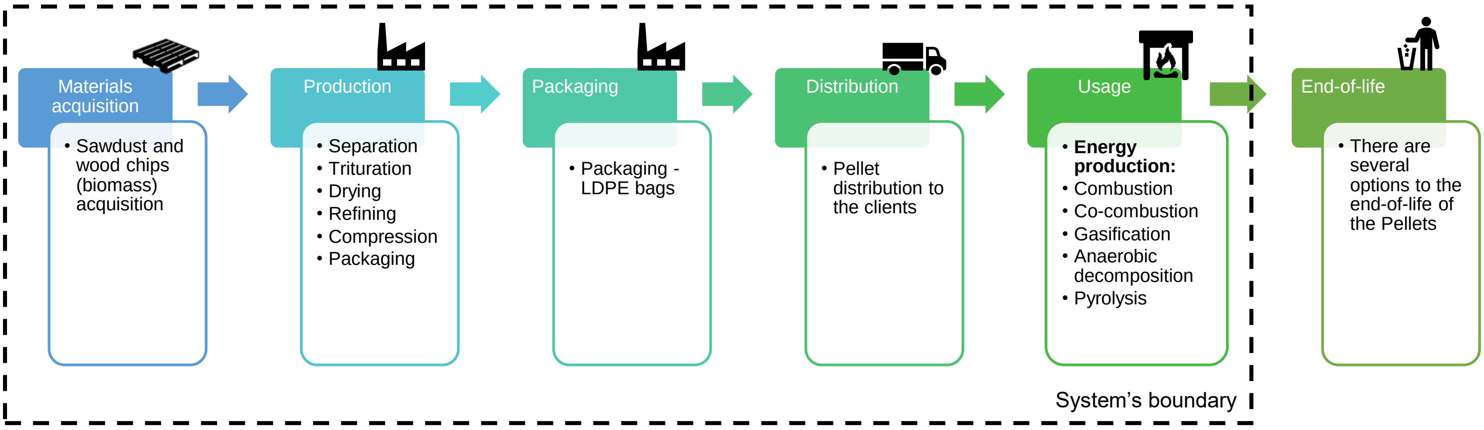

Figure 24 - Pellet's life cycle and system's boundary

The pellet's life cycle is here considered to be invariable (that does not change). The pellet's life The life cycle processes described in the present work are analogous to the ones studied by Quinteiro et al. (2019) and Ferreira et al. (2015). The combination of the analysis of these two works and the information gathered in the company's Webpage (Martos & Cª Lda., 2018b), generated the life cycle described below.

The first process in the pellet's life cycle is the **materials acquisition**. The materials mentioned are referring to the sawdust and wood chips[16], which are key materials needed to produce pellets. Figure 25 illustrates the sawdust and in Figure 26 one can observe the wood chips. Both materials are **by-products created during the production of pallets**.

Figure 25 - Sawdust (Madeca, 2018)

Figure 26 - Wood chips (Serração de Madeiras César Cardoso Correia, 2009)

These materials (sawdust and pine chips) are already inside the industrial unit, because the Omnipellets facility is in the same location as the Martos' pallet production facility. So, they do not need to be transported. Once again, these two materials are by-products generated during the pallet production process. This process (material acquisition) does not have any environmental impact since it is only the transfer of sawdust and wood chips to the pellet production area, which is right next to where they initially are. This process takes place in Omnipellets' facilities in Leiria, Portugal (the specific address, assumptions and reference are explained in detail in Appendix B – Figure 38 shows the life cycle processes locations).

The next step is the **production**. To start the production process, one proceeds to the trituration of the pine chips and sawdust, the idea is to get a homogeneous material that has smaller dimensions (similar to the sawdust dimensions). Normally, the material arrives with a moisture content of 40-50% and the pellets require a moisture content inferior to 10% (Ferreira et al., 2015). So, they need to be dried in order to be in the proper conditions for the following steps. Next, they are refined – the process uses steam injection into the dry sawdust, for the material to gain the agglomerate property required (Ferreira et al., 2015). And lastly, the material is compressed (or pelletized) in order to gain the perfect consistency and shape of the pellets. The production process takes place in the same location as the previous process (also in Leiria), and the assumptions to get to that conclusion are explained in Appendix B.

The next step is **packaging**. The product is put together in bags (Low-density polyethylene (LDPE) bags) containing 15kg of pellets with the dimensions 1200 x 1000 x 1800 mm. Then, they

[16] The wood chips will be mentioned as wood chips or pine chips. Pine chips because the wood used to produce the pallets in Martos' company comes from pine trees.

gather 70 bags of pellets and put them together in a pallet. The packaging process occurs in Leiria as well (explanation in Appendix B).

After having the product properly packed, they are ready to be **distributed**. Here, the Martosfrota company takes place and performs a key role. The product can also be bought via online, through their website, so it is transported directly to the customer. The pellets are distributed to several location inside Portugal. In order to simplify, three distinct locations were chosen: Bragança, Castelo Branco and Faro. The logic to get to these three locations is summed up in Appendix B (Table 23 and Figure 39).

The last process included in the system's boundary is denominated **usage**. The pellets are going to be combusted because their purpose is to give energy (heat).

The actual last process of pellet's life cycle is the end-of-life, which is not included in the system's boundary.

5.2.2.2 Step 2.2 – Inventory analysis (LCI)

Moving on to the inventory data tables, the first one is regarding the pellet production stage. The processes involved in the pellet production stage were explained in the previous subsection. The pellet production process is here, in Table 8, translated into raw materials, energy, water, air emissions, etc.

Table 8 - Inventory data per functional unit (pellet production)

Inputs/outputs	Quantity	Unit
Inputs:		
Wood chips	434.782,6	kg
Electricity	68.695.651	kWh
Diesel	373.913,04	kg
Sawdust	86.956,52	kg
Outputs:		
Pellets (produced)	434.782,6	kg
CO	1.017,3913	kg
CO_2 fossil	1.186.956,5	kg
NO_x	134.347,82	kg
SO_2	17.391,304	kg
CH_4 fossil	1.565,2174	kg
NMVOC	24,04348	kg
Ashes to landfill	11.826,087	kg
Wood waste	86.956,52	kg

The inventory list of the remaining processes of the pellets life cycle are in Tables 32 to 34 of Appendix B and the respective SimaPro references are displayed in Table 35 to 38 (Appendix B).

5.2.2.3 Step 2.3 – Impact assessment (LCIA)

The software and methods, as well as the midpoint categories chosen were all presented, and the choices justified, in Subsection 5.1.2.3. All the choices mentioned in the beginning of that subsection are also valid for the present one.

5.2.2.4 Step 2.4 – Interpretation

The first data to be analysed are the characterized values of the impact categories. Table 9 shows these values obtained using the ReCiPe method.

Table 9 - Characterized values per impact category obtained using the ReCiPe method (Pellets - E-LCA)

Impact category	Characterized value	Unit
GW	173202,4	kg CO2 eq
SOD	0,08922	kg CFC11 eq
IR	1473,29	kBq Co-60 eq
OF	1819,894	kg NOx eq
FPMF	396,5609	kg PM2.5 eq
TA	835,9695	kg SO2 eq
FE	7,781126	kg P eq
ME	1,922238	kg N eq
TEco	1239522	kg 1,4-DCB
FEco	217,3587	kg 1,4-DCB
MEco	926,876	kg 1,4-DCB
HCT	1944,177	kg 1,4-DCB
HNCT	37241,56	kg 1,4-DCB
LU	210450,9	m2a crop eq
MRS	348,0891	kg Cu eq
FRS	57976,61	kg oil eq
WC	2320,349	m3

These values alone cannot be analysed since they have different units. Later on, in Section 5.3 these values can be compared with the ones from the Corticeira Amorim CS. However, the approach here is to analyse the characterized values of the most concerning categories and to study what is causing it. But first, in order to understand which are the most worrying midpoint categories, one needs to look to its normalized values in order to be able to compare them. Figure 27 shows the Pareto analysis to the normalized values of the midpoint categories obtained using the ReCiPe method.

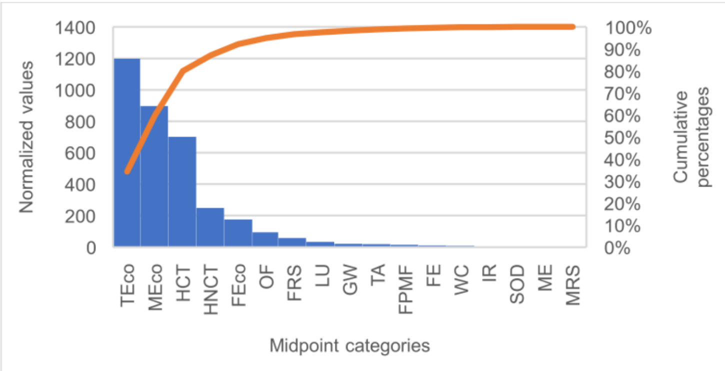

Figure 27 - Pareto analysis (midpoint categories) using ReCiPe – Pellets (E-LCA)

As one can observe in Figure 27, the first three categories (TEco, MEco and HCT) correspond to 80% of the total environmental impacts. The meaning of each categories is explained in Subsection 5.1.2.4, since these categories are also the most worrying ones in Corticeira Amorim's CS.

Figure 28 shows the Pareto analysis now applied to the midpoint categories of the IMPACT 2002+ method.

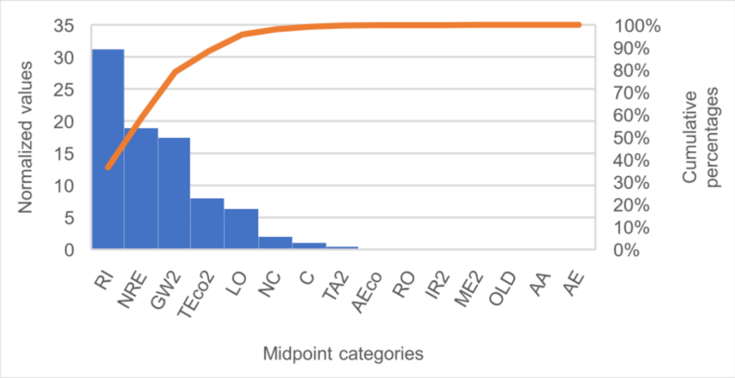

Figure 28 - Pareto analysis (midpoint categories) using IMPACT 2002+ – Pellets (E-LCA)

The first three categories shown in Figure 28 – RI, NRE and GW2 – make up about 80% of the total environmental impacts of the pellets life cycle. According to IMPACT 2002+, the most concerning category is the respiratory inorganics (category that corresponds to the FRS of ReCiPe, and according to that method it occupies the seventh place in the ranking of most worrying category). The second most worrying impact category is the non-renewable energy, which is the equivalent to the FPMF of ReCiPe. In the latter method, the category FPMF is considered to be the eleventh most concerning category. The category that is considered third in the worrying scale according to this method is the global warming, while in ReCiPe is considered to be nineth out of 17 categories (so more than halfway in the ranking). It is important to analyse different methods that bring new perspectives and also add information.

Since the most concerning impact categories are already identified, the conditions to go back and analyse the characterized values are gathered. Figure 29 shows the contribution of each pellets' life cycle process to the characterized values of the three categories identified as the most concerning ones using the ReCiPe method (see Figure 27).

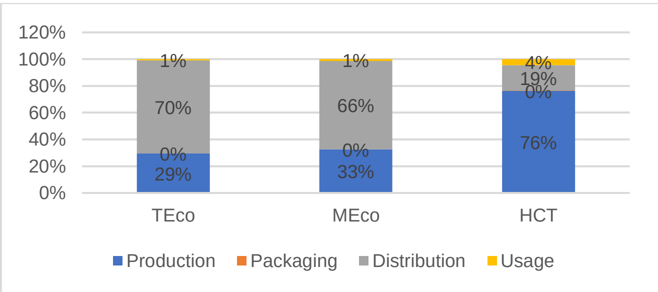

Figure 29 - Contribution of each process to the characterized values of the most relevant categories – Pellets (E-LCA)

So, starting this analysis with the **terrestrial ecotoxicity** category, as one can observe in Figure 29, the most relevant process is distribution (represents around 70% of this category impacts), followed by production (29%), usage (1%), and packaging (approximately 0%). The distribution stage impacts are entirely coming from the truck transportation. If one combines the truck and train transportation, the overall travelled distance is higher than when using just the truck. This happens because the truck has more flexibility (there are more roads than railways), while the train is more limited. For example, the railway to get to Castelo Branco requires the train to go first to Coimbra, then to Entroncamento and just then to Castelo Branco (which implies going up and down, opposing to what happens with the truck). So, for that reason, since the railway to Castelo Branco is considerably complex, two alternative scenarios are tested: one with using train in all three destinations (Bragança, Castelo Branco and Faro) (Scenario 1), and other that just uses train to Bragança and to Faro (Scenario 2). So, the first scenario provides a decrease of around 52% of the TEco characterized value, while the second scenario just decreases the TEco category in about 42%. However, it is important to keep in mind that even if the second scenario has a smaller decrease in this category, it still brings a big decrease and it is a more feasible scenario. The first scenario has a better performance in the majority of the impact category, but the second one wins when it comes to the OF, TA, FE, HCT and MRS categories. So, since the second scenario is a balance between the baseline scenario and the first improvement scenario and it is also more realistic, the suggestion would be to go with that one. Table 40 of Appendix C shows the comparison between the baseline scenario, Scenario 1 and Scenario 2 with the respective percentages of decrease in all impact categories.

Then, the next category under analysis is the **marine ecotoxicity**. Also in this category, the process accountable for the majority of the impacts is the distribution (represents around 66% of MEco impacts), followed by production (33%), usage (1%), and lastly the packaging process does not accommodate any impacts. Once again, the distribution process impacts are assigned to the truck transportation. So, the two alternative scenario previously mentioned are also valid for the present case. Table 40 of Appendix C shows all the alteration in the impact categories when changing the transportation mode. When it comes to the MEco category, these two scenario have a strong impact. Scenario 1 provides a decrease of 47% on the marine ecotoxicity impacts, and the second scenario allows a 38% decrease of this impacts. Similarly to what was proposed before, also here the final suggestion is to opt for the second scenario, since it also allows to reduction of this impacts and it is more feasible.

The third and last category under analysis in this part is the **human carcinogenic toxicity**. The case in this category is different from the previous two categories. Here, the process responsible for the majority of the HCT impacts is production (76%), followed by distribution (19%), and usage (4%). Once again, the packaging process does not have any HCT impacts. Around 89% of the production impacts correspond to the wood chips. Around 4% of the production process impacts in this category belongs to the sawdust input. Another 4% correspond to the electricity, and 3% to the ashes to the landfill. So, in order to decrease the HCT impacts, it would be valuable to decrease the amount of woodchips used in the process. With the reduction of the woodchips amount, what also comes is the reduction of the wood waste, which is also a positive outcome. So, in order to study the influence that the woodchips decrease has in the impact categories, two scenarios were analysed: first, a decrease of 20% of the woodchips (which implies no wood waste) and it was named Scenario 80%; and a second scenario with a smaller decrease of the woodchips, a decrease of only 10% (which includes a reduction in the wood waste, but still has some), which was named Scenario 90%. The second mentioned scenario was considered because the first one might be too radical and impossible to reach in reality, so an intermediate solution was proposed. Table 41 of Appendix C shows the two alternative scenario in comparison with the baseline scenario and the caused decreases in the impact categories. In the HCT category, the Scenario 80% provides a 18% decrease of the production impacts, while the Scenario 90% allows a decrease of 9%. It is important to study the efficiency of the production process because there is room for improvement and in the baseline scenario, the amounts of wood waste are quite relevant.

5.2.3 Step 3 – S-LCA application

This subsection consists of the S-LCA application (Step 3 in the methodology) to the production of **pellets** by Omnipellets. It consists of the application of S-LCA methodology to the CS and its four inherent sub-steps (Step 3.1 to 3.4), corresponding to subsections 5.2.3.1 to 5.2.3.4, respectively.

5.2.3.1 Step 3.1 – Goal and scope definition

Goal: The main goals are to learn about the social impacts of the pellets, to compare the pellets life cycle with the NCS and to formulate conclusions about the social impacts of the forest sector.

Scope:

Product characteristics: The product studied here is the same as the one of the E-LCA study (subsection 5.2.2), so its characteristics are exactly the same as described in the mentioned section.

Functional Unit: The quantity of product necessary to generate a revenue of 100.000 € per year.

Activity variable: Hours of work.

Boundary: The boundary is the same as used in Subsection 5.2.2 for the E-LCA study.

Life cycle: Also the life cycle of the pellets is the same as the one described in Subsection 5.2.2.

5.2.3.2 Step 3.2 – Inventory analysis (LCI)

This step consists of collecting the inventory (in terms of price, GTAP sector and country of origin) of each step of the pellets' life cycle. The values displayed in Table 10 are the final ones (ready to be introduced in the software), however, there is a three steps-process to get here. The explanation of this process is documented in Subsection 5.1.3.2.

So, Table 10 contains the inventory list of the pellets production stage in Portugal and the justification of these values is in Tables 51, 64 and 77 of Appendix D.

Table 10 - LCI of the pellet production stage in Portugal, for Omnipellets

Material	Price (USD 2011)	GTAP Sector Code	Country of origin[17]	Country percentage[18]
Wood chips	0,624372 USD2011 per kg	LUM	Portugal	32,6%
			Spain	67,4%
Electricity	0,156241 USD2011 per kWh	ELY	Portugal	83%
			Spain	17%
Diesel	1,257963 USD2011 per L	P_C	Spain	48,2%
			Russia	11,41%
			Belgium	11,26%
			Netherlands	9,04%
			China	3,97%
			Saudi Arabia	3,64%
			France	2,24%
			Italy	1,74%
			Egypt	1,49%
			Brazil	1,34%
Sawdust	0,05122 USD2011 per kg	LUM	Portugal	75,34%
			Spain	20,71%
			France	1,26%
			Germany	1,00%
			Belgium	0,48%
			Netherlands	0,42%
			Estonia	0,27%

The LCI of the remaining processes of the pellets life cycle are in Tables 88 to 90 of Appendix D. The references and calculations to get to the final results of the inventory list are displayed in Table 52 to 80 (Appendix D).

5.2.3.3 Step 3.3 – Impact assessment (LCIA)

The method selected to perform the LCIA step of the social LCA was Social Hotspot 2019 Subcategories & Categories Method with Damages. The method has five categories. These categories and sub-categories are already mentioned in Subsection 5.1.3.3 and the same is valid for the present subsection.

5.2.3.4 Step 3.4 – Interpretation

The first values to be analysed are the characterized values of the impact categories. Table 11 shows these values.

Table 11 - Characterized values per impact category (Pellets - S-LCA)

Impact category	Unit	Total
1A Wage	1A mrheq	60010,21
1B Poverty	1B mrheq	95140,91
1D Child Labor	1D mrheq	78957,81
1E Forced Labor	1E mrheq	94944,46
1F Excessive WkTime	1F mrheq	127924,2
1G Freedom of Assoc	1G mrheq	208662,5

[17] The countries from where the materials are imported and respective percentages were all taken from the Atlas of Economic Complexity (Growth Lab of Harvard University, 2020). The domestic production percentages were found through diverse methods.
[18] If the percentage of imports is lower than 0,05%, then it does not appear in the present table (Table 10) and the respective country will not be included in the calculations. The same is valid for all the similar tables (Table 88 to 90 of Appendix D).

Table 11 - Characterized values per impact category (Pellets - S-LCA) (Continuation)

Impact category	Unit	Total
1H Migrant Labor	1H mrheq	184459,2
1I Social Benefits	1I mrheq	50430,3
1J Labor Laws/Convs	1J mrheq	21288,24
1K Discrimination	1K mrheq	98177,91
1L Unemployment	1L mrheq	203920,7
2A Occ Tox & Haz	2A mrheq	155278,3
2B Injuries & Fatalities	2B mrheq	203234,5
3A Indigenous Rights	3A mrheq	35099,93
3B Gender Equity	3B mrheq	53979,32
3C High Conflict Zones	3C mrheq	157895,5
3D Non-Communicable Diseases	3D mrheq	24444,46
3E Communicable Diseases	3E mrheq	47727,68
4A Legal System	4A mrheq	73701,89
4B Corruption	4B mrheq	110587,3
5A Access to Drinking Water	5A mrheq	33860,19
5B Access to Sanitation	5B mrheq	70448,41
5C Children out of School	5C mrheq	92163,76
5D Access to Hospital Beds	5D mrheq	90657,03
5E Smallholder v Commercial Farms	5E mrheq	108766,2

Before analysing the values of Table 11, it is important to find which are the most relevant categories in order to be able to orientate the study. So, the best way to compare categories is by using its normalized values. Figure 30 shows the Pareto analysis applied to the normalized values of the midpoint categories.

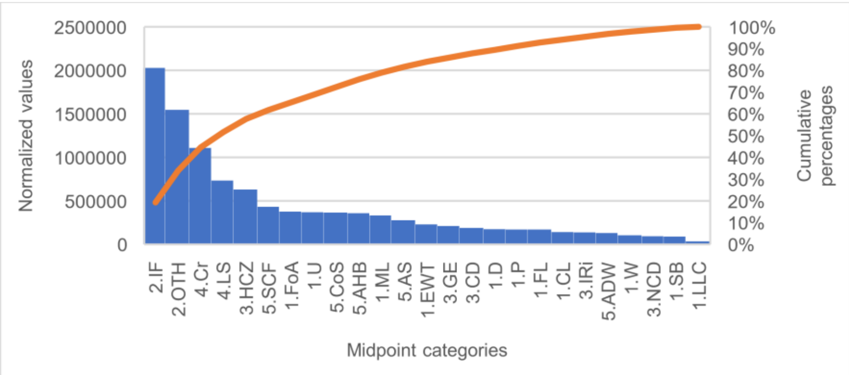

Figure 30 - Pareto analysis (midpoint categories) – Pellets (S-LCA)

According to Figure 30, the most impactful categories are, in order: IF, OTH, Cr, LS, HCZ, SCF, FoA, U, CoS, AHB and ML. These categories are explained in Subsection 5.1.3.4.

With the input of the most concerning categories, one can now go back to the characterization step. Figure 31 shows the contribution of the life cycle processes in the most relevant categories.

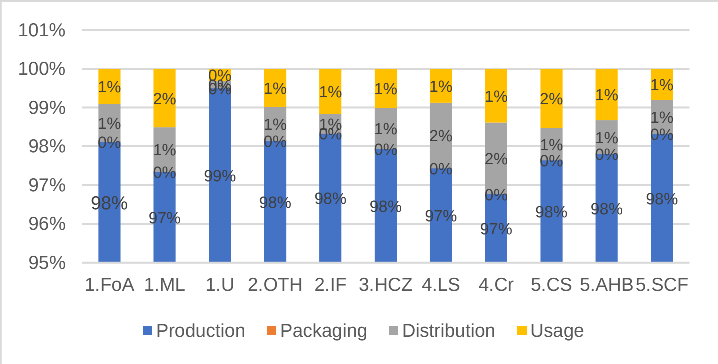

Figure 31 - Contribution of each process to the characterized values of the most relevant categories – Pellets (S-LCA)

According to Figure 30, the most impactful category is the **Injuries & Fatalities** (IF). As one can observe in Figure 31, the biggest process impacting the most this category is the production (around 98%). Secondly, the processes that comes after are the distribution and usage, with 1% each. The input of the production process that impacts the most this category is the wood chips from Spain (51%), then it is the wood chips from Portugal (45%) and lastly the sawdust and electricity from Portugal (both with 2%). The recommendation here is to analyse the wood chips industry in both Portugal and Spain in order to find safety measures to reduce the injuries and fatalities rates. The measures can be related with the workers uniforms, safety wearing, machinery, etc.

The second most worrying midpoint category is the **Occupational Toxics & Hazards** (OTH) (see Figure 30). According to Figure 31, this category follows the same trend set by the IF category. The production process gathers around 98% of the impacts, then the distribution and usage have both an impact of 1%. Looking in more detail to the production process, the input that is the most relevant one is the wood chips from Spain (63%). The second most impactful input of the production process is the wood chips from Portugal (33%). Then, with an importance of 2% of the production impacts, it comes the electricity (from Portugal). Lastly, the sawdust from Portugal has an impact of 1%. So, regarding the occupations toxics and hazards, the Spanish wood chips gains more relevance than in the injuries and fatalities category, when comparing to the Portuguese wood chips. The suggestion to reduce the impacts of this category is once more to look to the wood chips industry and to analyse the chemicals used that might be causing health problems to the workers.

If one changes the focus of the analysis from the impact categories to the processes, the analysis of Figure 31 can be done differently. As one can observe in Figure 31, the scale starts on the 95% to make the results easier to read. The production process contribution to the most impactful categories is between 96,8% (see subcategory Corruption in Figure 31) and 99,5% (see subcategory Unemployment in Figure 31). The distribution process contributes from 0,5-1,8% to these categories and the usage process from 0,8-2,7%. The packaging contributions are so minimal that are approximately 0% in all categories.

Since the production process has a prominent position, this process will be analysed in more detail. So, regarding the production process, the inputs contributing the most to the process impacts are the wood chips from Spain and then the wood chips from Portugal. The wood chips from Spain contribute on a range from 51% to 77%. The Spanish wood chips contributes the most to the following categories: Legal System (this input contributes around 77% to the production process impacts in this category), the High Conflict Zones (76%), the Freedom of Association (around 75%), the Smallholder vs Commercial Farms (74%) and the Corruption (about 71%). These issues are the most problematic ones when it comes to the wood chips sector in Spain. The wood chips coming from Portugal also have a strong impact in the social impacts of the production process (between 20-46%). In Portugal, the wood products sector reveals different issues than the ones shown by the Spanish sector. The most worrying categories to this product (in Portugal) are the Migrant Labor (46%), the Injuries & Fatalities (45%), and the Unemployment (40%). The other two products that have a contribution to the production process, even though that smaller, are the sawdust from Portugal and the electricity also from Portugal. The first mentioned input has a contribution in these categories of around 1 to 2%, while the second one shows percentages of contribution from 1-3%. The sawdust from Portugal shows the biggest concerns in the Migrant Labour area, in the Unemployment category and in the Injuries & Fatalities, similarly to the wood chips from Portugal, since they are from the same sector and same country. Regarding the Portugal electricity, the social areas of concern are the Migrant Labour and the Children out of School.

The distribution process relies on the fuel and this fuel comes from different origins. The origin countries that have the highest social impact are Spain, Russia, China and Egypt. The contribution that the Spanish fuel has in the impact categories fluctuates between 16-52% of the distribution process impact in the category. The areas of concern of this product in Spain are Access to Hospital Beds, Children out of School, Injuries & Fatalities, Unemployment and Freedom of Association. The Russian diesel contributes between 2-37% and the key issues are the Migrant Labor, Unemployment, Occupational Toxics & Hazards and the Corruption. China contributes from 0-26% of the social impact categories, and the most worrying categories are the Freedom of Association, the Occupational Toxics & Hazards, the Children out of School and the Smallholder vs Commercial Farms. Lastly, the Egyptian market of fuel contributes to this process from 2 to 28% and the social areas of concern are: Injuries & Fatalities, Legal System and Access to Hospital Beds.

The majority of the usage process impacts are related with the Portuguese electricity (between 79-91%) and another less relevant share with the Spanish electricity also (between 9-21%).

5.3 Step 4 – Comparison of systems

Environmental comparison

This section starts with the environmental comparison of the two systems (NCS and pellets) using the ReCiPe method. The first indicator to be compared are the midpoint categories, and then the analysis continues to the endpoint categories and single score. This analysis aims to compare the two systems to understand which one has a better environmental performance, but also to find the common points in order to formulate conclusions about the forest sector.

Table 12 shows the characterized values (of the midpoint categories) of the two systems under study side by side. In red are the higher values of each category, when comparing the two systems.

Table 12 - Comparison between the characterized values of NCS and Pellets (E-LCA)

Impact category	Characterized value (NCS)	Characterized value (Pellets)	Unit
GW	56308,019	173202,4	kg CO2 eq
SOD	0,17793568	0,08922	kg CFC11 eq
IR	330,71089	1473,29	kBq Co-60 eq
OF	515,77321	1819,894	kg NOx eq
FPMF	84,65925	396,5609	kg PM2.5 eq
TA	229,03125	835,9695	kg SO2 eq
FE	2,8969237	7,781126	kg P eq
ME	9,7259522	1,922238	kg N eq
TEco	232579,63	1239522	kg 1,4-DCB
FEco	78,037922	217,3587	kg 1,4-DCB
MEco	256,02601	926,876	kg 1,4-DCB
HCT	423,02995	1944,177	kg 1,4-DCB
HNCT	10617,133	37241,56	kg 1,4-DCB
LU	667806,2	210450,9	m2a crop eq
MRS	83,292909	348,0891	kg Cu eq
FRS	27709,848	57976,61	kg oil eq
WC	1377,0361	2320,349	m3

As one can observe in Table 12, the pellets life cycle have a worse performance in almost all of the impact categories. The exceptions are the Stratospheric Ozone Depletion (SOD), the Marine Eutrophication (ME) and the Land Use (LU), where the NCS life cycle presents a higher value. So, according to the midpoint categories, one can affirm that we are facing a trade-off, since the pellets CS have a better performance in some categories and the NCS in others. For that reason, one cannot formulate a conclusion about which case study is better from an environmental perspective.

However, when performing the Pareto analysis to the normalized values of both life cycle, one found that the most relevant categories in the NCS case are the Marine Ecotoxicity (MEco), Terrestrial Ecotoxicity (TEco), Human Carcinogenic Toxicity (HCT) and Land Use (LU), by order; and the most concerning ones of the pellets life cycle are the TEco, MEco and the HCT, by order. So, it is possible to conclude that these two systems have three categories in common as the most worrying one: TEco, MEco and HCT. Therefore, this indicates that these three environmental issues are, possibly, matters of concern to the forest sector.

Then, when a closer analysis to these categories was performed, it was concluded that the most impactful processes of these two life cycles are the production and distribution. In both cases, the distribution process (when on land) was being performed only by truck, and the possibility of using truck combined with train was studied and proved to be better in terms of environmental impacts. Regarding the production process, the biggest issues were related with the amount of raw materials used (cork and wood chips) and with the sources of energy. The suggestions to improve this process were to reduce the amount of raw materials used in the process (and consequently also reduce the waste) and to change the energy source to a greener one (either wind or solar). So, in a broader way, the recommendations given to the forest sector is to analyse the possible routes with the train and implement it as much as possible, to analyse the options regarding the energy sources and try to adapt/switch if possible to either wind or solar energy and lastly, to study the optimization of the raw materials use, in order to reduce the amounts used and consequently, the waste as well. If it is not possible to reduce the raw materials used, then to find ways to reuse the waste generated from the processes (for example, to use it as a way to generate energy for the process itself or to reintroduce in other production processes).

So, since the midpoint categories did not allow a conclusion regarding which CS has a better environmental performance, one moves on to the endpoint level. Figure 32 shows the three endpoint categories and enables the comparison between systems.

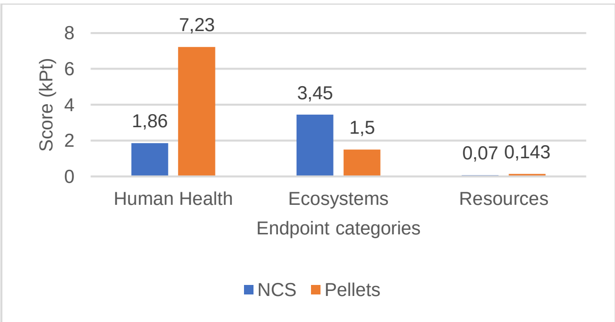

Figure 32 - Comparison of the endpoint categories - E-LCA

While the most worrying environmental endpoint category in the NCS case is the ecosystems, in the pellet's case is the human health. The human health and the resources categories present a higher value in the pellet's CS; and the ecosystems' category is led by the NCS. So, this means that this is, once more, a trade-off situation. Regarding the forest sector, the two biggest environmental areas of concern are the human health and the ecosystems.

Since the endpoint categories also show a trade-off, one moves to the last possible indicator – the single score. Figure 33 shows the values of the single scores of the two cases studies.

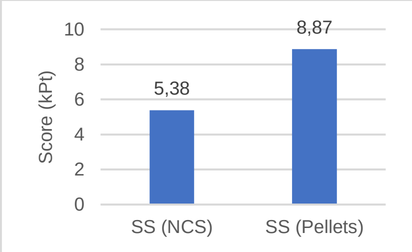

Figure 33 - SS (E-LCA) comparison

Figure 33 illustrates that the pellets' single score (8,87 kPt) is higher than the NCS's SS (5,38 kPt), which means that, overall, the pellets life cycle has a higher environmental impact than the NCS life cycle, for the same system boundary and functional unit.

Social comparison

Then, moving on to the social comparison, the first analysis to be performed is at the midpoint level. The comparison of these two systems is possible because they have the same functional unit and system's boundary. Table 13 shows the comparison between the impact categories characterized values of pellets and NCS life cycles. The values in red are the ones that are worse when comparing the two systems.

Table 13 - Comparison between the characterized values of NCS and Pellets (S-LCA)

Impact category	Unit	Characterized value (NCS)	Characterized value (Pellets)
1A Wage	1A mrheq	57323,69	60010,21
1B Poverty	1B mrheq	82931,46	95140,91
1D Child Labor	1D mrheq	79463,46	78957,81
1E Forced Labor	1E mrheq	106525,1	94944,46
1F Excessive WkTime	1F mrheq	53141,42	127924,2
1G Freedom of Assoc	1G mrheq	158942,8	208662,5
1H Migrant Labor	1H mrheq	203657,6	184459,2
1I Social Benefits	1I mrheq	38111,04	50430,3
1J Labor Laws/Convs	1J mrheq	21219,87	21288,24
1K Discrimination	1K mrheq	106744,2	98177,91
1L Unemployment	1L mrheq	58913,33	203920,7
2A Occ Tox & Haz	2A mrheq	121248,1	155278,3
2B Injuries & Fatalities	2B mrheq	135900,9	203234,5
3A Indigenous Rights	3A mrheq	42615,07	35099,93
3B Gender Equity	3B mrheq	71074,22	53979,32
3C High Conflict Zones	3C mrheq	112315,8	157895,5
3D Non-Communicable Diseases	3D mrheq	23597,01	24444,46
3E Communicable Diseases	3E mrheq	43394,33	47727,68
4A Legal System	4A mrheq	72384,94	73701,89
4B Corruption	4B mrheq	106343,9	110587,3
5A Access to Drinking Water	5A mrheq	52021,87	33860,19
5B Access to Sanitation	5B mrheq	52755,04	70448,41
5C Children out of School	5C mrheq	88630,38	92163,76
5D Access to Hospital Beds	5D mrheq	96957,16	90657,03
5E Smallholder v Commercial Farms	5E mrheq	105593,4	108766,2

The majority of the impact categories have a higher value in the pellets' life cycle. However, there are some exceptions. The categories where the NCS life cycle show a higher value are: Child

Labor, Forced Labor, Migrant Labor, Discrimination, Indigenous Rights, Gender Equity, Access to Drinking Water, and Access to Hospital Beds. The mentioned categories are a bigger issue to the NCS life cycle then to the pellets, while the others are the opposite. So, similarly to the environmental comparison, a trade-off is present in this situation. For that reason, the next parameter to be analysed are the endpoint categories. But firstly, an overview to the forest sector is performed.

So, when the Pareto Rule was applied to the normalized values of the impact categories (Subsections 5.1.3.4 and 5.2.3.4), the most concerning categories were found. Between the most relevant categories of these two systems, the ones that are common are the Freedom of Association, Migrant Labor, Occupational Toxics & Hazards, Injuries & Fatalities, High Conflict Zones, Legal System, Corruption, Children out of School, Access to Hospital Beds, and Smallholder vs Commercial Farms. So, since these categories are common, they are considered to be the biggest social issues of the forest sector.

Regarding the life cycle processes, during the results analysis it was proved that the most worrying process to the NCS life cycle is the forest management and the production, and in the pellets' life cycle is the production. Since the common point is the production point, that is the one considered to be the most worrying and the one to be watched in the forest sector. Besides that, the countries that had more impact in the systems life cycle were Portugal and Spain (and also Morocco in the NCS case). However, the countries that contribute the most to the social impacts of a life cycle will always depend on the life cycle locations (and the countries from where products are imported), which can be very different from company to company. One thing that can always be done is to learn about the rules of the countries that the company operates in, the workers' rights, etc., and observe to understand if there is any danger of social problems. Regarding the forest sector, since the two main countries identified were Portugal and Spain and the biggest issues in these countries were related with injuries, fatalities and occupational toxics and hazards, the main recommendations are to reinforce the security in the job with more protection and close attention to the safety of the workers (for example, implementing safety clothing, measures, etc.).

Moving on to the next analysis, Figure 34 shows the comparison of the endpoint categories between the two systems under study.

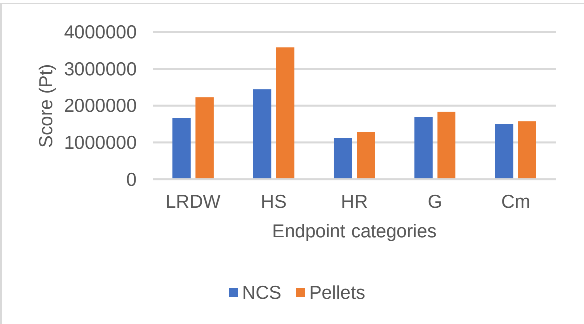

Figure 34 - Comparison of the endpoint categories - S-LCA

At the endpoint categories, the pellets' case study has a higher value in all categories, which means that the pellets have a worse social performance than the NCS. The ranking order of the endpoint categories is almost the same, the only changes are in the labour rights & decent work category and in the governance. The first mentioned category occupies the second place in the pellet's case and the third in the NCS's one, while the latter one has the exact opposite behaviour. So, this means that the forest sector has its biggest social issues in the health & safety category, then in the labour rights & decent work and in the governance. These three categories are the most worrying social issues to this sector.

Even though it was already concluded at the endpoint level that the pellets CS has a worse social performance, Figure 35 shows the social single scores of NCS and pellets life cycles, and it reinforces the mentioned conclusion.

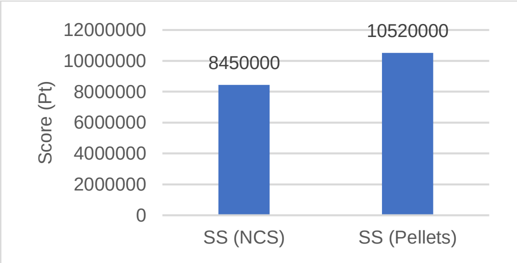

Figure 35 - SS (S-LCA) comparison

So, according to Figure 35, the pellets life cycle have a higher SS than the NCS, which indicates that the pellets have a worse social performance.

6. Conclusions and Future Work

The motivation of this dissertation was to investigate the environmental and social impacts of a cork and a forest bioenergy product (using E-LCA and S-LCA methodologies, respectively, to assess those impacts). The idea was to understand how to apply the same methodologies to two different products and be able to compare them. The only connection between these two products is that they belong to the same business sector – the forest sector -, which was used to withdraw conclusions about this sector. So, the added value that this work aimed to bring is to apply the E-LCA and S-LCA methodology (in a harmonized way, and quite synchronized) to two distinct systems and still be able to compare them, which is not so common.

One of the challenges faced was that the majority of the literature analysed do not apply these methodologies to compare products that are so different, with such different applications as well. So, the main outcome taken from the analysis of the literature was the guidelines to apply the methodologies (the four steps of LCA). Even though these methodologies are not one hundred percent homogenous (which can be proven by the different names that different authors give to the same things), the proposal here was to standardize and use a methodology common to both environmental and social pillars (the LCA methodology) with the same nomenclature and coherence. Therefore, the main contribution of the present work is to provide a methodology that is common to both environmental and social LCA and to apply these methodologies to distinct product, with different applications.

In order to apply the mentioned methodologies, one opted for using two different case studies. One is the Corticeira Amorim (corresponding to the cork CS) and the other is Omnipellets (corresponding to the forest bioenergy CS). The products chosen to study were the natural cork stoppers (NCS) and the pellets. In addition to the products being different, also these two companies are quite different, as well as its supply chain. That is why it was interesting to study two diverse universes, with its inherent dissimilar features. Corticeira Amorim is a worldwide company (with a supply chain beyond national borders), while Omnipellets only has presence in Portugal.

The application of the two methodologies (E-LCA and S-LCA) allowed to conclude that, to generate a revenue of 100.000€, the pellet production is worse than the natural cork stoppers production, both in social and environmental terms. Besides that, throughout the analysis performed it was able to identify some similarities between the case studies. In a broad way, regarding the environmental field, the major key issues of the forest sector are the human health and the ecosystems. The human health endpoint category is more worrying in the pellets CS, while the ecosystems one is more concerning in the NCS life cycle. If one looks in more detail and zooms in to the midpoint level, the environmental problems are similar in both CSs. By order, the most concerning midpoint categories in the NCS case are the MEco, TEco, HCT and the LU. While in the pellets case, the most worrying ones are the TEco, MEco and HCT, by order. The three first categories, even though in a different order, are common to the two case studies, which might indicate that the forest sector may find environmental issues in these three categories. When moving on to the social department, the identified social areas of concern in the forest sector are: FoA, ML, U, OTH, IF, HCZ, LS, Cr, CS, AHB, SCF, GE and AS; which converted into endpoint indicators show that the most relevant categories are the HS, the LRDW and the G.

Lastly, regarding the future work, a suggestion is to try to develop a LCA methodology for the economic pillar of sustainability, in order to have the three LCAs for the three pillars. Besides that, it would be valuable to have more guidance and guidelines for the application of these methodologies, as well as conformity in the information and existing literature. Particularly to the S-LCA case (since it is the least studied one), it would be important to practice the coherence between studies, because it is more in the beginning of its development. Also regarding the S-LCA methodology but now more in the user perspective (in this case in SimaPro with SHDB), it would be interesting to have the inventory list more disaggregated (with more business sectors), because it is putting a lot of different products all in the same category, which sounds a bit reducer. These are some of the suggestions that occurred during the process of developing the present dissertation.

Bibliography

Abbas, D., & Handler, R. M. (2018). Life-cycle assessment of forest harvesting and transportation operations in Tennessee. *Journal of Cleaner Production*, *176*, 512–520. https://doi.org/10.1016/j.jclepro.2017.11.238

Adams, P. W. R., Shirley, J. E. J., & McManus, M. C. (2015). Comparative cradle-to-gate life cycle assessment of wood pellet production with torrefaction. *Applied Energy*, *138*, 367–380. https://doi.org/10.1016/j.apenergy.2014.11.002

African Development Bank. (2015). Rail Infrastructure in Africa. Retrieved 3 November 2020, from https://www.afdb.org/fileadmin/uploads/afdb/Documents/Events/ATFforum/Rail_Infrastructure_in_Africa_-_Financing_Policy_Options_-_AfDB.pdf

Agro Popular. (2017). El precio del corcho se estanca y suben los costes de producción. Retrieved 28 July 2020, from Informativos Agrarios S.L. website: https://www.agropopular.com/corcho-precio-estanca-costes-produccion/

Águas de Portugal. (2019). *RELATÓRIO DE SUSTENTABILIDADE 2019*. Retrieved from https://www.adp.pt/pt/sustentabilidade/relatorios-de-sustentabilidade/downloads/file310_pt.pdf

Águas de Santarém. (2020). Tarifário Geral Domésticos e Não Domésticos. Retrieved 10 July 2020, from https://aguasdesantarem.pt/clientes/tarifario-2019/geral-2019/

Al-Arab Al-Youm Media. (2020). *No Title*. Retrieved from https://www.almaghribtoday.net/244/193310-سعر-الغاز-
الطبيعي-يتراجع-لأدنى-مستوى-منذ-2016

Algérie Électricité. (2020). Prix d’un kWh en Algérie. Retrieved 5 August 2020, from https://algerie-electricite.com/faq/prix-kwh

Amorim Cork Composites S.A. (2018). Cork Oak Forest. Retrieved 28 December 2019, from Why Cork website: https://amorimcorkcomposites.com/en/why-cork/facts-and-curiosities/about-oak-forest/

APCOR. (2015a). *Cork Sector in Numbers*.

APCOR. (2015b). Natural Cork Stoppers. Retrieved 21 June 2020, from https://www.apcor.pt/en/cork/processing/industrial-path/natural-cork-stoppers/

APCOR. (2018). APCOR – Floresta. Retrieved 2 June 2019, from http://www.apcor.pt/montado/floresta/

APCOR. (2019). *Cork Sector in Numbers*. Retrieved from https://www.apcor.pt/wp-content/uploads/2019/02/CORK-SECTOR-IN-NUMBERS_EN.pdf

Ayer, N. W., & Dias, G. (2018). Supplying renewable energy for Canadian cement production: Life cycle assessment of bioenergy from forest harvest residues using mobile fast pyrolysis units. *Journal of Cleaner Production*, *175*, 237–250. https://doi.org/10.1016/j.jclepro.2017.12.040

Bacovsky, D., Ludwiczek, N., Pointner, C., & Kumar Verma, V. (2016). *IEA Bioenergy Countries’ Report: Bioenergy policies and status of implementation*. 120. Retrieved from http://www.ieabioenergy.com/wp-content/uploads/2016/09/IEA-Bioenergy-Countries-Report-23.09.2016.pdf

Barbier, E. B. (1987). *The Concept of Sustainable Economic Development*. London: International Institute for Environment and Development.

Beagle, E., & Belmont, E. (2019). Comparative life cycle assessment of biomass utilization for electricity generation in the European Union and the United States. *Energy Policy*, *128*(January), 267–275. https://doi.org/10.1016/j.enpol.2019.01.006

Beattie, A. (2019). The 3 Pillars of Corporate Sustainability. *Investopedia*. Retrieved from https://www.investopedia.com/articles/investing/100515/three-pillars-corporate-sustainability.asp

Benoit-Norris, C., Traverso, M., Valdivia, S., Vickery-Niederman, G., Franze, J., & Azuero, L. (2013). The Methodological Sheets for Sub-Categories in Social Life Cycle Assessment (S-LCA). *Pre-Publication Version*. https://doi.org/10.1007/978-1-4419-8825-6

Borrion, A. L., Khraisheh, M., & Benyahia, F. (2012). Environmental life cycle impact assessment of Gas-to-Liquid processes. In *Proceedings of the 3rd Gas Processing Symposium* (3rd ed., pp. 71–77). Qatar.

Brander, M. (2018). Comparative analysis of attributional corporate greenhouse gas accounting, consequential life cycle assessment, and project/policy level accounting: A bioenergy case study. *Journal of Cleaner Production*, *167*, 1401–1414. https://doi.org/10.1016/j.jclepro.2017.02.097

Brooks, W. H. (1997). *A Literature Review of California Domestic Cork Production*. 479–484.

Buonocore, E., Paletto, A., Russo, G. F., & Franzese, P. P. (2019). Indicators of environmental performance to assess wood-based bioenergy production: A case study in Northern Italy. *Journal of Cleaner Production*, *221*(2019), 242–248. https://doi.org/10.1016/j.jclepro.2019.02.272

Calc Hub, L. (2020). Million BTU to Kilowatt-hours Conversion. Retrieved 19 August 2020, from https://www.inchcalculator.com/convert/million-btu-to-kilowatt-hour/

Cambero, C., Hans Alexandre, M., & Sowlati, T. (2015). Life cycle greenhouse gas analysis of bioenergy generation alternatives using forest and wood residues in remote locations: A case study in British Columbia, Canada. *Resources, Conservation and Recycling*, *105*, 59–72. https://doi.org/10.1016/j.resconrec.2015.10.014

CEFIC. (2020). *FACTS & FIGURES of the European chemical industry*. Retrieved from https://cefic.org/app/uploads/2019/01/The-European-Chemical-Industry-Facts-And-Figures-2020.pdf

Cenários Gulosos. (2020). Ácido Cítrico. Retrieved 10 July 2020, from https://www.cenarios-gulosos.pt/produto/acido-citrico-cg-0000004/?gclid=Cj0KCQjwo6D4BRDgARIsAA6uN1_nu79lZQQxRPo12fV35HArT-2AnLweXgfjAHa9vEMRWrwhLLOAliwaArCoEALw_wcB

Center for Global Trade Analysis. (2020). GTAP Data Bases: Detailed Sectoral List. Retrieved 9 September 2020, from https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector.asp

CIA. (2020). The World Factbook - Africa :: Algeria. Retrieved 21 August 2020, from https://www.cia.gov/library/publications/the-world-factbook/geos/ag.html

CIP. (2015). *Logística em Portugal*. Retrieved from http://cip.org.pt/wp-content/uploads/2017/01/Ref-99.pdf

Circular Ecology Ltd. (2020). Life Cycle Assessment (LCA). Retrieved 8 April 2020, from https://www.circularecology.com/lca.html

Cork Quality Council. (2017). Industry Statistics. Retrieved 24 August 2020, from https://www.corkqc.com/pages/industry-statistics

Corticeira Amorim. (2015a). Environmental and Social benefits - Why Cork. Retrieved 11 December 2019, from Corticeira Amorim, Cork Sector World Leader website: https://www.amorim.com/en/why-cork/environmental-and-social-benefits/

Corticeira Amorim. (2015b). Mission, Vision and Values - Who are we. Retrieved 11 December 2019, from Corticeira Amorim, Cork Sector World Leader website: https://www.amorim.com/en/who-are-we/mission-vision-and-values/

Corticeira Amorim. (2015c). Raw-Materials. Retrieved 30 December 2019, from https://www.amorim.com/en/business-units/raw-materials/

Corticeira Amorim. (2015d). Social Responsibility - Who are we. Retrieved 11 December 2019, from Corticeira Amorim, Cork Sector World Leader website: https://www.amorim.com/en/who-are-we/social-responsibility/

Corticeira Amorim. (2015e). WORLDWIDE PRESENCE. Retrieved 22 June 2020, from https://www.amorim.com/en/who-are-we/worldwide-presence/

Corticeira Amorim. (2018). *Relatório de Sustentabilidade 2018*. Retrieved from https://www.amorim.com/xms/files/Sustentabilidade/Relatorios/relatorio_sustentabilidade_2018_web_2.pdf

CYPE Ingenieros, S. A. (2020). Gerador de preços. Portugal. Retrieved 13 July 2020, from http://www.geradordeprecos.info/obra_nova/Revestimentos/Pinturas_em_madeira/Vernizes/Verniz_de_agua.html

da Costa, T. P., Quinteiro, P., Tarelho, L. A. da C., Arroja, L., & Dias, A. C. (2018). Environmental impacts of forest biomass-to-energy conversion technologies: Grate furnace vs. fluidised bed furnace. *Journal of Cleaner Production*, *171*, 153–162. https://doi.org/10.1016/j.jclepro.2017.09.287

de la Fuente, T., Athanassiadis, D., González-García, S., & Nordfjell, T. (2017). Cradle-to-gate life cycle assessment of forest supply chains: Comparison of Canadian and Swedish case studies. *Journal of Cleaner Production*, *143*, 866–881. https://doi.org/10.1016/j.jclepro.2016.12.034

de la Fuente, T., Bergström, D., González-García, S., & Larsson, S. H. (2018). Life cycle assessment of decentralized mobile production systems for pelletizing logging residues under Nordic conditions. *Journal of Cleaner Production*, *201*, 830–841. https://doi.org/10.1016/j.jclepro.2018.08.030

Demertzi, M., Dias, A. C., Matos, A., & Arroja, L. M. (2015). Evaluation of different end-of-life management alternatives for used natural cork stoppers through life cycle assessment. *Waste Management*, *46*, 668–680. https://doi.org/10.1016/j.wasman.2015.09.026

Demertzi, M., Garrido, A., Dias, A. C., & Arroja, L. (2015). Environmental performance of a cork floating floor. *Materials and Design*, *82*, 317–325. https://doi.org/10.1016/j.matdes.2014.12.055

Demertzi, M., Paulo, J. A., Arroja, L., & Dias, A. C. (2016). A carbon footprint simulation model for the cork oak sector. *Science of the Total Environment*, *566–567*, 499–511. https://doi.org/10.1016/j.scitotenv.2016.05.135

Demertzi, M., Sierra-Pérez, J., Paulo, J. A., Arroja, L., & Dias, A. C. (2017). Environmental performance of expanded cork slab and granules through life cycle assessment. *Journal of Cleaner Production*, *145*, 294–302. https://doi.org/10.1016/j.jclepro.2017.01.071

Demertzi, M., Silva, R. P., Neto, B., Dias, A. C., & Arroja, L. (2016). Cork stoppers supply chain: Potential scenarios for environmental impact reduction. *Journal of Cleaner Production*, *112*, 1985–1994. https://doi.org/10.1016/j.jclepro.2015.02.072

DGEG. (2020). Preço dos Combustíveis Online. Retrieved 13 July 2020, from http://www.precoscombustiveis.dgeg.pt/default.aspx?cn=6298AAAAAAAAAAAAAAAAAAAA

DieseloGasolina. (2020). Precio de la gasolina y diésel HOY España. Retrieved 30 July 2020, from https://www.dieselogasolina.com/

DND. (2020). Hempel Hard Racing Teccel 2.5lt. Retrieved 10 July 2020, from https://www.dnd.pt/pt/produto/1419-hempel-hard-racing-teccel-25lt

EIA. (2017). SPAIN. Retrieved 19 August 2020, from https://www.eia.gov/international/analysis/country/ESP

Environmental Science. (2020). What Is Sustainability and Why Is It Important? Retrieved 6 September 2020, from https://www.environmentalscience.org/sustainability

Fabriprint. (2020). Tinta alimentar. Retrieved 10 July 2020, from https://www.fabriprint.pt/tinta-alimentar-para-reenchimento-500-ml.html

FAO. (2015). *Profil de Pays – Algérie*. Retrieved from http://www.fao.org/3/i9861fr/I9861FR.pdf

Favre, M., & Montginoul, M. (2018). Water pricing in Tunisia: Can an original rate structure achieve multiple objectives? *Utilities Policy*, *55*(October), 209–223. https://doi.org/10.1016/j.jup.2018.06.004

Fedorova, E., & Pongrácz, E. (2019). Cumulative social effect assessment framework to evaluate the accumulation of social sustainability benefits of regional bioenergy value chains. *Renewable Energy*, *131*, 1073–1088. https://doi.org/10.1016/j.renene.2018.07.070

Ferreira, I., Fernandes, M., & Nunes, C. (2015). *Solução Integrada de Valorização de Resíduos Florestais*. Instituto Superior Técnico.

Ganguly, I., Pierobon, F., Bowers, T. C., Huisenga, M., Johnston, G., & Eastin, I. L. (2018). 'Woods-to-Wake' Life Cycle Assessment of residual woody biomass based jet-fuel using mild bisulfite pretreatment. *Biomass and Bioenergy*, *108*(September 2016), 207–216. https://doi.org/10.1016/j.biombioe.2017.10.041

Garcia-Ceballos, L., de Andres-Díaz, J. R., & Contreras-Lopez, M. A. (2018). Life cycle study of different constructive solutions for building enclosures. *Science of the Total Environment*, *626*, 1167–1174. https://doi.org/10.1016/j.scitotenv.2018.01.109

Giuntoli, J., Caserini, S., Marelli, L., Baxter, D., & Agostini, A. (2015). Domestic heating from forest logging residues: Environmental risks and benefits. *Journal of Cleaner Production*, *99*, 206–216. https://doi.org/10.1016/j.jclepro.2015.03.025

GlobalPetrolPrices. (2020a). Algeria Diesel prices, 03-Aug-2020. Retrieved 10 August 2020, from https://www.globalpetrolprices.com/Algeria/diesel_prices/

GlobalPetrolPrices. (2020b). Algeria natural gas prices. Retrieved 11 August 2020, from https://www.globalpetrolprices.com/Algeria/natural_gas_prices/

GlobalPetrolPrices. (2020c). Morocco Diesel prices, liter, 10-Aug-2020. Retrieved 10 August 2020, from https://www.globalpetrolprices.com/Morocco/diesel_prices/

GlobalPetrolPrices. (2020d). Morocco electricity prices. Retrieved 10 August 2020, from https://www.globalpetrolprices.com/Morocco/electricity_prices/

GlobalPetrolPrices. (2020e). Tunisia electricity prices. Retrieved 10 August 2020, from https://www.globalpetrolprices.com/Tunisia/electricity_prices/

GlobalPetrolPrices. (2020f). Tunisia Gasoline prices. Retrieved 10 August 2020, from https://www.globalpetrolprices.com/Tunisia/gasoline_prices/

Goedkoop, M., Heijungs, R., Huijbregts, M., Schryver, A. De, Struijs, J., & van Zelm, R. (2013). *ReCiPe 2008*.

Grazimadeiras. (2020). Serradura de pinho. Retrieved 3 August 2020, from http://www.grazimadeiras.pt/produtos/5

Growth Lab of Harvard University. (2020). The Atlas of Economic Complexity. Retrieved 23 July 2020, from https://atlas.cid.harvard.edu/

Grupo Vitalino. (2020). Catalizador líquido Reaktol 20 ML. Retrieved 13 July 2020, from https://www.grupovitalino.pt/product/catalizador-liquido-reaktol-20-ml

Hach. (2020). Solução padrão de cloreto de sódio, 1000 µS/cm (NIST), 100 mL. Retrieved 10 July 2020, from https://pt.hach.com/solucao-padrao-de-cloreto-de-sodio-1000-s-cm-nist-100-ml/product-details?id=24929818489

Havukainen, J., Nguyen, M. T., Väisänen, S., & Horttanainen, M. (2018). Life cycle assessment of small-scale combined heat and power plant: Environmental impacts of different forest biofuels and replacing district heat produced from natural gas. *Journal of Cleaner Production*, *172*, 837–846. https://doi.org/10.1016/j.jclepro.2017.10.241

ICNF. (2018). *Síntese Económica 2018*. Retrieved from http://www2.icnf.pt/portal/florestas/fileiras/econ

IEA. (2015). *Energy Policies of IEA Countries: Spain 2015*. Retrieved from https://webstore.iea.org/download/direct/360

IEA. (2016). *Energy Policies of IEA Countries - Portugal 2016*.

ILO. (2020). International Labour Organization. Retrieved 14 November 2020, from https://www.ilo.org/global/lang--en/index.htm

Inapa packaging. (2020). SACO PLASTICO PEBD 50 x 85 CM x 70 MY. Retrieved 3 August 2020, from https://inapapackaging.pt/21158-saco-plastico-pebd-50-x-85-cm-x-70-my#.XyfouyhKjIU

IndexMundi. (2019a). Espanha. Retrieved 21 August 2020, from https://www.indexmundi.com/pt/espanha/

IndexMundi. (2019b). Marrocos. Retrieved 21 August 2020, from https://www.indexmundi.com/pt/marrocos/

IndexMundi. (2019c). Portugal Gás natural - produção. Retrieved 21 August 2020, from https://www.indexmundi.com/pt/portugal/gas_natural_producao.html

IndexMundi. (2019d). Tunísia. Retrieved 21 August 2020, from https://www.indexmundi.com/pt/tunisia/

IndexMundi. (2020a). Fueloil Precio Diario. Retrieved 5 August 2020, from https://www.indexmundi.com/es/precios-de-mercado/?mercancia=fueloil

IndexMundi. (2020b). Óleo combustível Preço Diário. Retrieved 13 July 2020, from https://www.indexmundi.com/pt/preços-de-mercado/?mercadoria=óleo-combustível&meses=12

IndexMundi. (2020c). Portugal. Retrieved 21 August 2020, from https://www.indexmundi.com/pt/portugal/

IndiaMART. (2019). Biomass - Pellets. Retrieved 11 December 2019, from https://www.indiamart.com/proddetail/biomass-pellets-7007793388.html

INE. (2018). *Estatísticas da Produção Industrial - 2018*. Retrieved from https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_publicacoes&PUBLICACOESpub_boui=358631083&PUBLICACOESmodo=2

ISO. (2006a). ISO 14040:2006 - Environmental management -- Life cycle assessment -- Principles and framework. Retrieved 2 June 2019, from https://www.iso.org/standard/37456.html

ISO. (2006b). ISO 14044:2006 - Environmental management -- Life cycle assessment -- Requirements and guidelines. Retrieved 2 June 2019, from https://www.iso.org/standard/38498.html

ISO. (2017). ISO 15686-5. Retrieved 17 September 2020, from https://www.iso.org/obp/ui/#iso:std:iso:15686:-5:ed-2:v1:en

Jiran, N. S., Mahmood, S., Saman, M. Z. M., & Yusof, N. M. (2013). Review on Methodology for Life Cycle Costing of Membrane System for Wastewater Filtration. *Advanced Materials Research*. https://doi.org/10.4028/www.scientific.net/AMR.845.713

La Rosa, A. D., Recca, A., Gagliano, A., Summerscales, J., Latteri, A., Cozzo, G., & Cicala, G. (2014). Environmental impacts and thermal insulation performance of innovative composite solutions for building applications. *Construction and Building Materials*, *55*, 406–414. https://doi.org/10.1016/j.conbuildmat.2014.01.054

La Rosa, A. D., Recca, G., Summerscales, J., Latteri, A., Cozzo, G., & Cicala, G. (2014). Bio-based versus traditional polymer composites. A life cycle assessment perspective. *Journal of Cleaner Production*, *74*, 135–144. https://doi.org/10.1016/j.jclepro.2014.03.017

Lauw, A., Oliveira, V., Lopes, F., & Pereira, H. (2017). Variation of cork quality for wine stoppers across the production regions in Portugal. *European Journal of Wood and Wood Products*, *76*(1), 123–132. https://doi.org/10.1007/s00107-017-1196-5

Leroy Merlin. (2020). Esmalte antioxidante e anticorrosivo. Retrieved 10 July 2020, from https://www.leroymerlin.pt/Produtos/Tintas-e-drogaria/Produtos-para-metal/Tinta-para-ferro/WPR_REF_12273786

Li, J., Wang, Y., & Yan, B. (2018). The hotspots of life cycle assessment for bioenergy: A review by social network analysis. *Science of the Total Environment*, *625*, 1301–1308. https://doi.org/10.1016/j.scitotenv.2018.01.030

Linde Portugal. (2020). Dióxido Enxofre 3.0. Retrieved 10 July 2020, from https://www.linde-gas.pt/shop/pt/pt-ig/dióxido-enxofre-30-p-dióxido-enxofre-30

Liu, H., Huang, Y., Yuan, H., Yin, X., & Wu, C. (2018). Life cycle assessment of biofuels in China: Status and challenges. *Renewable and Sustainable Energy Reviews*, Vol. 97, pp. 301–322. https://doi.org/10.1016/j.rser.2018.08.052

Liu, W., Zhu, Q., Zhou, X., & Peng, C. (2019). Comparative analyses of different biogenic CO 2 emission accounting systems in life cycle assessment. *Science of the Total Environment*, *652*, 1456–1462. https://doi.org/10.1016/j.scitotenv.2018.11.039

Loja dos Químicos. (2020). Bissulfato de Sódio. Retrieved 13 July 2020, from https://www.lojadosquimicos.pt/product/bissulfato-de-sodio/

LojaPro. (2020). PARAFINA EM BARRA 5 QUILOS. Retrieved 10 July 2020, from https://www.lojapro.pt/parafina-em-barra.html?gclid=Cj0KCQjwo6D4BRDgARIsAA6uN19XTJkIT1UPHaqOq8Od-bzjkn8v_xsJRDORZH3PATwaGC0n3WSc1xsaAnEWEALw_wcB

LuckyVitamin LLC. (2020). Peróxido de Hidrogênio Grau Alimentício. Retrieved 10 July 2020, from https://pt.luckyvitamin.com/p-2664160-heritage-hydrogen-peroxide-food-grade-3-usp-16-fl-oz

Macombe, C., Leskinen, P., Feschet, P., & Antikainen, R. (2013). Social life cycle assessment of biodiesel production at three levels: A literature review and development needs. *Journal of Cleaner Production*, *52*, 205–216. https://doi.org/10.1016/j.jclepro.2013.03.026

Madeca. (2018). Serrim. Retrieved 24 June 2020, from https://madeca.pt/?action=serrim

MADIPLAC – Madeira e Derivados. (2020). PELLETS. Retrieved 9 September 2020, from https://madiplac.pt/pellets/

Mahbub, N., Oyedun, A. O., Kumar, A., Oestreich, D., Arnold, U., & Sauer, J. (2017). A life cycle assessment of oxymethylene ether synthesis from biomass-derived syngas as a diesel additive. *Journal of Cleaner Production*, *165*, 1249–1262. https://doi.org/10.1016/j.jclepro.2017.07.178

Martos & Cª Lda. (2018a). Apresentação. Retrieved 11 December 2019, from https://www.martos.pt/apresentacao/

Martos & Cª Lda. (2018b). Benefícios na utilização de Pellets. Retrieved 11 December 2019, from https://www.martos.pt/pellets-beneficios/

Martos & Cª Lda. (2018c). Missão. Retrieved 11 December 2019, from https://www.martos.pt/missao/

Martos & Cª Lda. (2018d). Produtos. Retrieved 30 December 2019, from https://www.martos.pt/pellets-produtos/

Martos & Cª Lda. (2018e). Visão. Retrieved 11 December 2019, from https://www.martos.pt/visao/

Mattila, T. J., Judl, J., Macombe, C., & Leskinen, P. (2018). Evaluating social sustainability of bioeconomy value chains through integrated use of local and global methods. *Biomass and Bioenergy*, *109*(December 2017), 276–283. https://doi.org/10.1016/j.biombioe.2017.12.019

Meadows, D. L., Meadows, D., Randers, J., & Behrens III, W. W. (1972). *Limits to Growth*. Potomac Associates.

MECALUX. (2019). Paletes de madeira. Retrieved 11 December 2019, from MECALUX - logismarket website: https://www.logismarket.pt/paletes-madeira/1584345-cp.html

Medialdea, S. (2020). El precio del agua en Madrid seguirá congelado por quinto año. *ABC Madrid*. Retrieved from https://www.abc.es/espana/madrid/abci-precio-agua-madrid-seguira-congelado-sexto-202001310046_noticia.html?ref=https:%2F%2Fwww.google.com%2F

Ministry for the Environment Manatú Mo Te Taiao. (2020). Appendix A: Impact Category Descriptions. Retrieved 28 September 2020, from https://www.mfe.govt.nz/publications/waste/life-cycle-assessment-product-stewardship-options-mercury-containing-lamps-new-1

MIPMED. (2020). Álcool Etílico. Retrieved 10 July 2020, from https://mipmed.com/ethyl-alcohol-70-and-96

Miscota. (2020). Trixie Lascas de madeira de faia, extra fino. Retrieved 14 July 2020, from https://www.miscota.pt/repteis/trixie/p-16198?r=4011905761459&gclid=CjwKCAjwr7X4BRA4EiwAUXjbtw3voYiqt-KVsFp5qnlJrbdMMaqaHYG8x1uW2AK9U-j9uDBqHT-4AhoC4qcQAvD_BwE

Morales, M., Aroca, G., Rubilar, R., Acuña, E., Mola-Yudego, B., & González-García, S. (2015). Cradle-to-gate life cycle assessment of Eucalyptus globulus short rotation plantations in Chile. *Journal of Cleaner Production*, *99*, 239–249. https://doi.org/10.1016/j.jclepro.2015.02.085

Morales, M., Quintero, J., Conejeros, R., & Aroca, G. (2015). Life cycle assessment of lignocellulosic bioethanol: Environmental impacts and energy balance. *Renewable and Sustainable Energy Reviews*, Vol. 42, pp. 1349–1361. https://doi.org/10.1016/j.rser.2014.10.097

Morningstar. (2020). Morningstar | Empowering Investor Success. Retrieved 24 August 2020, from https://www.morningstar.com/

Muazu, R. I., Borrion, A. L., & Stegemann, J. A. (2017). Life cycle assessment of biomass densification systems. *Biomass and Bioenergy*, pp. 384–397. https://doi.org/10.1016/j.biombioe.2017.10.026

Muñoz, E., Curaqueo, G., Cea, M., Vera, L., & Navia, R. (2017). Environmental hotspots in the life cycle of a biochar-soil system. *Journal of Cleaner Production*, *158*, 1–7. https://doi.org/10.1016/j.jclepro.2017.04.163

Muthu, S. S. (2014). Estimating the overall environmental impact of textile processing: life cycle assessment (LCA) of textile products. *Assessing the Environmental Impact of Textiles and the Clothing Supply Chain*, 105–131. https://doi.org/10.1533/9781782421122.105

Neste. (2020). Basic concepts of lubricants.

Norris, C. B., Norris, G. A., Cavan, D. A., & Benoit, P. (2016). *SHDB 2.1 - Supporting Documentation*.

OLX. (2020). Lubrificante Multifunções com TEFLON®. Retrieved 10 July 2020, from https://www.olx.pt/anuncio/lubrificante-multifunes-com-teflon-IDA8uAH.html#ec9e68579c

Omnipellets. (2020). Especificações Técnicas. Retrieved 13 September 2020, from https://omnipellets.pt/pellets/especificacoes-tecnicas/

Ostermiller, S. (2020). CoinMill.com - O Conversor Da Moeda corrente. Retrieved 10 August 2020, from https://pt.coinmill.com/EGP_EUR.html

Palmeros Parada, M., Osseweijer, P., & Posada Duque, J. A. (2017). Sustainable biorefineries, an analysis of practices for incorporating sustainability in biorefinery design. *Industrial Crops and Products*, *106*, 105–123. https://doi.org/10.1016/j.indcrop.2016.08.052

Pargana, N., Pinheiro, M. D., Silvestre, J. D., & De Brito, J. (2014). Comparative environmental life cycle assessment of thermal insulation materials of buildings. *Energy and Buildings*, *82*, 466–481. https://doi.org/10.1016/j.enbuild.2014.05.057

Patel, M., Zhang, X., & Kumar, A. (2016). Techno-economic and life cycle assessment on lignocellulosic biomass thermochemical conversion technologies: A review. *Renewable and Sustainable Energy Reviews*, Vol. 53, pp. 1486–1499. https://doi.org/10.1016/j.rser.2015.09.070

PEFC. (2019a). Benefits of forests. Retrieved 19 December 2019, from Why forests are important website: https://www.pefc.org/what-we-do/why-forests-are-important/the-benefits-of-forests

PEFC. (2019b). Sustainable Develpment Goals. Retrieved 19 December 2019, from What we do website: https://pefc.org/what-we-do/sustainable-development-goals/page/1

PEFC. (2019c). What is PEFC? Retrieved 17 December 2019, from Discover PEFC website: https://www.pefc.org/discover-pefc/what-is-pefc

PEFC. (2019d). Why forests are important. Retrieved 17 December 2019, from PEFC - What we do website: https://www.pefc.org/what-we-do/why-forests-are-important

PEFC Portugal. (2017). Floresta Portuguesa. Retrieved 17 December 2019, from Certificação GFS website: https://www.pefc.pt/certificacao-gfs/introducao/floresta-portuguesa

Petrillo, A., De Felice, F., Jannelli, E., & Minutillo, M. (2017). Chapter 5 - Life Cycle Cost Analysis of Hydrogen Energy Technologies. In *Hydrogen Economy: Supply Chain, Life Cycle Analysis and Energy Transition for Sustainability* (pp. 121–138). https://doi.org/https://doi.org/10.1016/B978-0-12-811132-1.00005-5

PRé Consultants. (2019). LCA methodology: the 4 steps of life cycle assessment | PRé Sustainability. Retrieved 2 June 2019, from https://www.pre-sustainability.com/sustainability-consulting/lca-methodology-basics

PRé Sustainability. (2012). ReCiPe. Retrieved 28 September 2020, from https://pre-sustainability.com/articles/recipe/

Pré Sustainability B.V. (2020). Recorded Webinar | Updated Social Hotspots Database in SimaPro. Retrieved 13 September 2020, from https://support.simapro.com/articles/Video/Recorded-Webinar-Updated-Social-Hotspots-Database-in-SimaPro/?l=en_US&fs=RelatedArticle

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. *Sustainability Science*.

Quinteiro, P., Tarelho, L., Marques, P., Martín-gamboa, M., Freire, F., Arroja, L., & Dias, A. C. (2019). Life cycle assessment of wood pellets and wood split logs for residential heating. *Science of the Total Environment*, *689*, 580–589. https://doi.org/10.1016/j.scitotenv.2019.06.420

Railcc. (2020). Barcelona to Lisbon by train. Retrieved 3 November 2020, from https://rail.cc/train/barcelona-to-lisbon

Restaurar&Conservar. (2020). Hidróxido de sódio NaOH Frasco. Retrieved 10 July 2020, from http://www.restaurarconservar.com/Hidroxido-de-sodio-NaOH

RIVM. (2018). LCIA: the ReCiPe model. Retrieved 28 September 1BC, from https://www.rivm.nl/en/life-cycle-assessment-lca/recipe

RNE. (2020). RAIL FREIGHT CORRIDORS GENERAL INFORMATION. Retrieved 3 November 2020, from https://rne.eu/rail-freight-corridors/rail-freight-corridors-general-information/

Röder, M., Whittaker, C., & Thornley, P. (2014). How certain are greenhouse gas reductions from bioenergy? Life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues. *Biomass and Bioenergy*, *79*, 50–63. https://doi.org/10.1016/j.biombioe.2015.03.030

Roos, A., & Ahlgren, S. (2018). Consequential life cycle assessment of bioenergy systems – A literature review. *Journal of Cleaner Production*, Vol. 189, pp. 358–373. https://doi.org/10.1016/j.jclepro.2018.03.233

RTR Modelismo, L. (2020). SILICON OIL 800 - 50ML. Retrieved 10 July 2020, from https://rtr-modelismo.com/pt/acessorios-oleosilicone-amortecedores/99546-silicon-oil-800-50ml.html

Ruiz, D., San Miguel, G., Corona, B., & López, F. R. (2018). LCA of a multifunctional bioenergy chain based on pellet production. *Fuel*, *215*(January 2016), 601–611. https://doi.org/10.1016/j.fuel.2017.11.050

Russo Garrido, S. (2017). Social Life-Cycle Assessment: An Introduction. In *Encyclopedia of Sustainable Technologies* (Vol. 1). https://doi.org/10.1016/B978-0-12-409548-9.10089-2

Santos, A., Carvalho, A., Barbosa-Póvoa, A. P., Marques, A., & Amorim, P. (2019). Assessment and optimization of sustainable forest wood supply chains – A systematic literature review. *Forest Policy and Economics*, *105*(February), 112–135. https://doi.org/10.1016/j.forpol.2019.05.026

Selectra. (2020a). kWh: Como calcular o preço da eletricidade e gás natural em Portugal. Retrieved 10 July 2020, from https://selectra.pt/energia/info/faq/kwh-preco

Selectra. (2020b). Precio del kWh de gas natural en 2020. Retrieved 30 July 2020, from https://preciogas.com/faq/precio-kwh

Selectra. (2020c). Precio del kWh en España en 2020. Retrieved 30 July 2020, from https://tarifaluzhora.es/info/precio-kwh

Serração de Madeiras César Cardoso Correia. (2009). Estilha. Retrieved 24 June 2020, from http://www.cesarcorreia.com/pt/catalogo/produtos_show/scripts/core.htm?p=catalogo&f=produtos_show&lang=pt&id=519&title=Estilha

Sierra-Pérez, J., García-Pérez, S., Blanc, S., Boschmonart-Rives, J., & Gabarrell, X. (2018). The use of forest-based materials for the efficient energy of cities: Environmental and economic implications of cork as insulation material. *Sustainable Cities and Society*, *37*(December 2017), 628–636. https://doi.org/10.1016/j.scs.2017.12.008

Sierra-Pérez, Jorge, Boschmonart-Rives, J., Dias, A. C., & Gabarrell, X. (2016). Environmental implications of the use of agglomerated cork as thermal insulation in buildings. *Journal of Cleaner Production*, *126*, 97–107. https://doi.org/10.1016/j.jclepro.2016.02.146

Sierra-Pérez, Jorge, & Durany, X. G. (2015). Production and trade analysis in the Iberian cork sector: economic characterization of a forest industry. *Resources Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2015.02.011

Sierra-Pérez, Jorge, Rodríguez-Soria, B., Boschmonart-Rives, J., & Gabarrell, X. (2018). Integrated life cycle assessment and thermodynamic simulation of a public building's envelope renovation: Conventional vs. Passivhaus proposal. *Applied Energy*, *212*(December 2017), 1510–1521. https://doi.org/10.1016/j.apenergy.2017.12.101

Silva, M. E., & Figueiredo, M. D. De. (2020). Practicing sustainability for responsible business in supply chains. *Journal of Cleaner Production*, 119621. https://doi.org/10.1016/j.jclepro.2019.119621

Spindler, E. A. (2013). The History of Sustainability The Origins and Effects of a Popular Concept. In I. Jenkins & R. Schröder (Eds.), *Sustainability in Tourism* (pp. 9–31).

STEG. (2020). Société Tunisienne de l'Électricité et du Gaz. Retrieved 19 August 2020, from https://www.steg.com.tn/ar/clients_res/tarif_electricite.html

Tagliaferri, C., Evangelisti, S., Clift, R., & Lettieri, P. (2018). Life cycle assessment of a biomass CHP plant in UK: The Heathrow energy centre case. *Chemical Engineering Research and Design*, *133*, 210–221. https://doi.org/10.1016/j.cherd.2018.03.022

Tártaro, A. S., Mata, T. M., Martins, A. A., & Esteves da Silva, J. C. G. (2017). Carbon footprint of the insulation cork board. *Journal of Cleaner Production*, *143*, 925–932. https://doi.org/10.1016/j.jclepro.2016.12.028

Traffic Media. (2019). No Title. Retrieved 11 December 2019, from https://0.trafficlmedia.com/?p=miywmn3cg45gi3bpge4dana&sub1=Cobb&sub2=travel.v3

UNESCO. (2017). Introducing UNESCO: what we are. Retrieved 6 September 2020, from http://www.unesco.org/new/en/united-nations-educational-scientific-and-cultural-organization/about-us/who-we-are/introducing-unesco/

United Nations. (2020a). THE 17 GOALS. Retrieved 6 September 2020, from https://sdgs.un.org/goals

United Nations. (2020b). United Nations. Retrieved 6 September 2020, from https://www.un.org/en/

VideVersus. (2019). Biocarvão pode ser usado para recuperar solo degradado, indica estudo de Agnieska Latawiec. Retrieved 11 December 2019, from https://www.videversus.com.br/biocarvao-pode-ser-usado-para-recuperar-solo-degradado-indica-estudo-de-agnieska-latawiec/

von Carlowitz, H. C. (1713). *Sylvicultura oeconomica*.

Webster, I. (2020). CPI Inflation Calculator. Retrieved 24 August 2020, from https://www.in2013dollars.com/us/inflation/2011?amount=1

WLPGA. (2015). KEY MARKET – MOROCCO.

World Commission on Environment and Development. (1987). *Our Common Future - Brundtland report*. Oxford University Press.

World Health Organization. (2020). Water, sanitation and hygiene (WASH). Retrieved 14 November 2020, from https://www.who.int/health-topics/water-sanitation-and-hygiene-wash

World Wildlife Fund. (2019). Northern Africa: Morocco, Algeria, and Tunisia. Retrieved 30 December 2019, from https://www.worldwildlife.org/ecoregions/pa1214

Zabalza Bribián, I., Aranda Usón, A., & Scarpellini, S. (2009). Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. *Building and Environment*, *44*(12), 2510–2520. https://doi.org/10.1016/j.buildenv.2009.05.001

Zidi, W., & Daly, H. (2019). *Indicateurs clés sur La forêt, les produits et services forestiers en Tunisie*.

Appendix A

Table 14 – E-LCA categories, respective normalization and weighting factors, subcategories, and respective factors

Damage category / Unit	Normalization factor	Weighting factor	Impact category	Impact category factor
Human Health (DALY)	42,1	400	Global warming	1
			Stratospheric ozone depletion	1
			Ionizing radiation	1
			Ozone formation	1
			Fine particulate matter formation	1
			Human carcinogenic toxicity	1
			Human non-carcinogenic toxicity	1
			Water consumption	1
Ecosystems (species.yr)	1396	400	Global warming (Terrestrial ecosystems)	1
			Global warming (Freshwater ecosystems)	1
			Ozone formation	1
			Terrestrial acidification	1
			Freshwater eutrophication	1
			Marine eutrophication	1
			Terrestrial ecotoxicity	1
			Freshwater ecotoxicity	1
			Marine ecotoxicity	1
			Land use	1
			Water consumption (Terrestrial ecosystems)	1
			Water consumption (Aquatic ecosystems)	1
Resources (USD2013)	0,0000357	200	Mineral resources scarcity	1
			Fossil resources scarcity	1

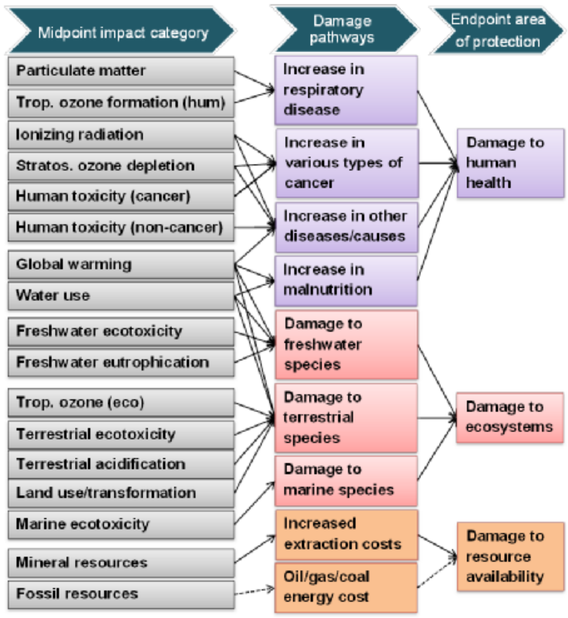

Figure 36 - Relationship between the midpoint category (left) and endpoint category (right) in ReCiPe 2016. (RIVM, 2018)

Table 15 - Social Issues and Weights used to Calculate the Social Hotspot Index for each Category (Norris et al., 2016)

Category	Theme	Issue	Weight
Labour Rights & Decent Work	Wage Assessment	Risk of Sector Ave Wage being lower than Country's Non-poverty Guideline	1,5
	Wage Assessment	Risk of Sector Ave Wage being lower than Country's Minimum Wage	1,5
	Poverty	Risk of Wages being under $2 per day	1,5
	Forced Labour	Risk of Forced Labour by Sector (used country level risk [not shown] if no sector data was found)	1,5
	Child Labour	Risk of Child Labour in sector, Total (used country-level risk where no sector data was found)	1,5
	Working time	Risk of excessive working time by sector (used country level risk [not shown] where no sector data exists)	1,5
	Freedom of Association, Collective Bargaining, and Right to Strike	Risk that a country lacks or does not enforce Freedom of Association rights	1,5
	Freedom of Association, Collective Bargaining, and Right to Strike	Risk that a country lacks or does not enforce Collective Bargaining rights	1,5
	Freedom of Association, Collective Bargaining, and Right to Strike	Risk that a country lacks or does not enforce the Right to Strike	1,5
	Migrant Workers	Risk that migrant workers are treated unfairly (based on qualitative literature review)	1
Health & Safety	Occupational Injuries & Deaths	Risk of non-fatal injuries by sector	1,5
	Occupational Injuries & Deaths	Risk of fatal injury by sector	1,5
	Occupational Toxics & Hazards	Risk of workplace noise exposure, both genders	1
	Occupational Toxics & Hazards	Risk of loss of life or death by exposure to carcinogens in occupation	1
	Occupational Toxics & Hazards	Risk of loss of life by airborne particulates in occupation	1
Human Rights	Indigenous Rights	Risk that indigenous people are negatively impacted at sector level	1,5
	High Conflict Zones	Overall Risk for High Conflict-increased if risk exists at sector level	1,5
	Gender Equity	Overall Risk of Gender Inequality in country	1,5
	Gender Equity	Risk of Gender inequality by Sector based on representation in the workforce	1
	Human Health - Noncommunicable Diseases and other health risks	Risk of mortality from non-communicable diseases	1
	Human Health – Communicable Diseases	Risk of mortality from communicable diseases	1
Governance	Legal System	Risk of fragility in the legal system considering all indicators	1,5
	Corruption	Overall Risk of Corruption considering all indicators	1,5
Community Infrastructure	Access to Improved Drinking Water	Risk of no access to an Improved Source of Drinking Water	1,5
	Access to Improved Sanitation	Risk of no access to an Improved source of Sanitation	1,5
	Access to Hospital Beds	Risk that there are too few hospital beds to support population	1

Table 16 - GTAP Sectors and respective code (Norris et al., 2016)

GTAP Sector Code	GTAP Sector	GTAP Sector Code	GTAP Sector	GTAP Sector Code	GTAP Sector
ATP	Air transport	OFD	Food products nec	PFB	Plant-based fibers
OAP	Animal products nec	FRS	Forestry	PCR	Processed rice

Table 16 - GTAP Sectors and respective code (Norris et al., 2016) (Continuation)

GTAP Sector Code	GTAP Sector	GTAP Sector Code	GTAP Sector	GTAP Sector Code	GTAP Sector
B_T	Beverages and tobacco products	GDT	Gas manufacture, distribution	OSG	Public Administration, Defense, Education, Health
CTL	Bovine cattle, sheep and goats, horses	GAS	Gas	RMK	Raw milk
CMT	Bovine meat products	ISR	Insurance	ROS	Recreational and other services
OBS	Business services nec	LEA	Leather products	C_B	Sugar cane, sugar beet
GRO	Cereal grains nec	OME	Machinery and equipment	SGR	Sugar
CRP	Chemical, rubber, plastic products	OMF	Manufactures nec	TEX	Textiles
COA	Coal	OMT	Meat products nec	TRD	Trade
CMN	Communication	FMP	Metal products	OTN	Transport equipment nec
CNS	Construction	NFM	Metals nec	OTP	Transport nec
OCR	Crops nec	NMM	Mineral products nec	VOL	Vegetable oils and fats
MIL	Dairy products	OMN	Minerals nec	V_F	Vegetables, fruits, nuts
DWE	Dwellings	MVH	Motor vehicles and parts	WTP	Water transport
ELY	Electricity	OSD	Oil seeds	WTR	Water
ELE	Electronic equipment	OIL	Oil	WAP	Wearing apparel
I_S	Ferrous metals	PDR	Paddy rice	WHT	Wheat
OFI	Financial services nec	PPP	Paper products, publishing	LUM	Wood products
FSH	Fishing	P_C	Petroleum, coal products	WOL	Wool, silk-worm cocoons

Appendix B

Environmental Life Cycle Assessment

Locations assumptions (life cycle processes)

- **CORTICEIRA AMORIM**

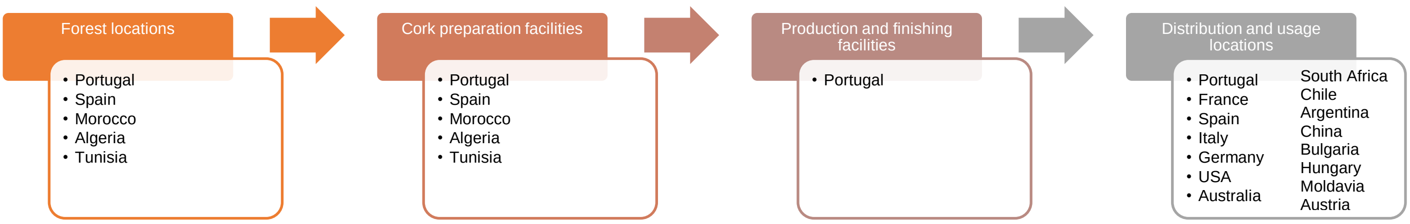

Figure 37 - NCS's life cycle (locations)

Forest locations

The first locations to take into account are the forest locations. In the Sustainability Report of 2018 (Corticeira Amorim, 2018), the company mentions their cork purchases, as shown in Table 17.

Table 17 - Cork purchases in thousands of euros for the year 2018 (Corticeira Amorim, 2018)

Location	Cork purchase (thousands of euros)	Purchase percentage
Portugal	189.673	72%
North of Africa	10.909	4%
Other sources	62.407	24%
Total	262.989	100%

Table 18 - Final percentages of cork purchases per country

Country	Percentage[19] (of raw cork purchases)
Portugal	72%
Spain	24%
Tunisia[20]	2%
Morocco	1%
Algeria	1%

[19] The percentages presented in Table 18 will be valid from the forest stage until de production and finishing stage, only changing when it comes to the distribution stage.
[20] Tunisia shows up with a higher percentage than the remaining countries belonging to North of Africa because Tunisia has more than one cork preparation facility, while the others only have one (Corticeira Amorim, 2015e).

Cork preparation facilities

Table 19 - Addresses of the cork preparation facilities (Corticeira Amorim, 2015e)

Location	Address
Portugal1	Rua dos Corticeiros, 850 Apartado 1, 4536-904 Santa Maria de Lamas
Portugal2	Ponte de Sôr Industrial Unit, Zona Industrial Nova, Rua B 7400-401 Ponte de Sôr
Portugal3	Coruche Industrial Unit, Zona Industrial Monte da Barca 2100-051 Coruche
Portugal4	Abrantes Industrial Unit, E.N. nº 2 – Km 412,15 Vale de Cortiças 2205-583 S. Miguel do Rio Torto - Abrantes
Portugal5	Salteiros Industrial Unit, Lugar de Salteiros – Longomel 7400-402 Ponte de Sôr
Spain1	S. V. Alcántara Industrial Unit, Polígono Industrial, S/N 06500 – San Vicente de Alcántara, Badajoz
Spain2	Algeciras Industrial Unit, Carretera de Castellar, S/N 11368 – Estación de San Roque, Cádiz
Spain3	Catalunya Industrial Unit C/ Roselló, 18, 17244 Càsa de la Selva, Girona
Morocco	Km. 26 – RP nº1 From Rabat to Casablanca 12050 Skhirat
Tunisia1	Route de Aïn Draham 8110 Tabarka, Tunisia
Tunisia2	1, Rue des travailleurs, 2010 la Mannouba
Tunisia3	Route de Aïn Draham 8110 Tabarka
Argelia	Z.I. nº 47 Ouled-Salah Taher BP nº A.74-RP – Jijel (18000)

Table 20 - Distances to travel with cork from the forests to the cork preparation facilities

Location	Road distance (km)	Sea distance (km)
Portugal1	222	0
Portugal2	37	0
Portugal3	0	0
Portugal4	10	0
Portugal5	41	0
Spain1	53	0
Spain2	137	37
Spain3	50	0
Morocco	260	0
Tunisia1	95	0
Tunisia2	75	0
Tunisia3	91	0
Argelia	420	0

Production and finishing facilities

The addresses of the production/finishing units are (Corticeira Amorim, 2015e):

- **PTprod 1**: Rua dos Corticeiros, nr 850. 4536-904 Santa Maria de Lamas;
- **PTprod 2**: Zona Industrial do Monte da Barca. 2100-051 Coruche.

Table 21 - Distances from the cork preparation facilities to the production/finishing facilities

Cork preparation unit:	Goes to (production/finishing):	Sea distance (km)	Road distance (km)
Portugal1	PTprod 1	0	0
Portugal2	PTprod 2	0	64
Portugal3	PTprod 2	0	0
Portugal4	PTprod 2	0	80
Portugal5	PTprod 2	0	67
Spain1	PTprod 2	0	174
Spain2	PTprod 2	0	569
Spain3	PTprod 1	0	1.178
Morocco	PTprod 2	40	900
Tunisia1	PTprod 2	200	2.000
Tunisia2	PTprod 2	200	2.180
Tunisia3	PTprod 2	200	2.020
Argelia	PTprod 2	200	1.700

Distribution locations

It was assumed that the distribution and usage locations are the same.

Table 22 - Percentage of the overall NCS distribution by country (APCOR, 2019; Corticeira Amorim, 2015e; Demertzi, Silva, et al., 2016)

Country	Percentage	Truck (km)	Ship (km)
Portugal	11%	70	0
France	20%	1.800	0
Spain	14%	785	0
Italy	11%	2.457	0
Germany	8%	2.221	0
USA	18%	2.792	14.005
Australia	3%	11	18.550
South Africa	3%	52	9.780
Chile	4%	1.415	10.155
Argentina	2%	1.062	10.155
China	2%	3.224	18.841
Bulgaria	1%	3.618	0
Hungary	1%	3.142	0
Moldavia	1%	4.189	0
Austria	1%	2774	0

- **OMNIPELLETS**

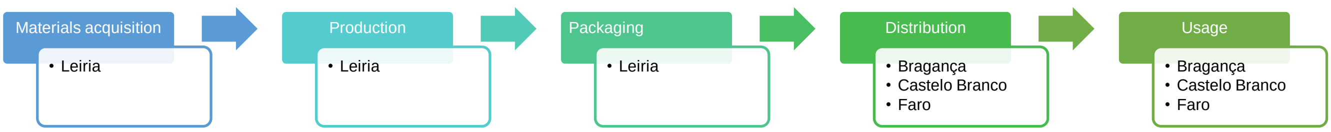

Figure 38 - Pellet's life cycle locations

Material acquisition, production and packaging location

The location of all the life cycle processes mentioned above is in Colmeias, Leiria, Portugal (address: Rua Nossa Senhora de Fátima 200 Zona Industrial das Areias, 2420-193 Leiria).

Distribution locations

Since Omnipellets sells to all Portugal, in order to simplify, three different distribution locations were picked: Bragança, Castelo Branco and Faro (and then almost all Portuguese territory is covered – see Figure 39). Table 23 shows the travel distances from Leiria to all final destinations.

Table 23 - Distribution locations and respective distances

Origin	Destination	Distance (km)
Leiria	Bragança	358
Leiria	Castelo Branco	169
Leiria	Faro	385

Label:
L – Leiria
B – Bragança
CB – Castelo Branco
F – Faro

Figure 39 - Pellet distribution locations

LCI step – (E-LCA)

- **CORTICEIRA AMORIM**

Table 24 – Inventory data per functional unit (NCS production) (Demertzi et al. (2016)) (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Electricity	12.330,05	kWh
Lubricating oil	436,5867	L
Natural gas	7.485,35	m^3
Water	861,9067	m^3
NaOH	985,841	kg
H_2O_2	2.366,018	kg
$NaHSO_4$	44,36285	kg
Citric Acid	44,36285	kg
Enzyme catalyst for H_2O_2	2,81669	kg
Antifouling mix	1,22526	kg
Anticorrosive	1,22526	kg
NaCl	24,64603	kg
Ethyl alcohol	302,794	L
Water based coverings	1.408,344	kg
Cork planks	98.584,1	kg
Transport – truck (ROW)	24.783,76	tkm
Transport – ship	630,9382	tkm
Outputs:		
NCS (unfinished)	29.575,23	kg
Cork residues	69.008,87	kg
Sludge	313,3566	kg
Wastewater	145,7636	m^3

Table 25 - Inventory data per functional unit (NCS finishing) (Demertzi et al. (2016)) (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
NCS (unfinished)	29.575,23	kg
Electricity	15.186,18	kWh
Paint	3,52086	kg
Silicone oil	84,50067	kg
Paraffin	415,4616	kg
SO_2	28,16689	kg
Outputs:		
NCS	28.166,89	kg
Cork residues	1408,345	kg

Table 26 - NCS distribution to each country (in tkm) – by truck and/or ship (E-LCA)

Country	Truck (tkm)	Ship (tkm)
Portugal	216,88505	0
France	10.140,0804	0
Spain	3.095,54121	0
Italy	7.612,66536	0
Germany	5.004,69302	0
USA	14.155,5522	71005,913
Australia	9,29507	15674,874
South Africa	43,94035	8264,1655
Chile	1.594,24597	11441,391
Argentina	598,26474	5720,6954
China	1.816,20107	10613,847
Bulgaria	1.019,07808	0
Hungary	885,00368	0
Moldavia	1.179,91102	0
Austria	781,34953	0

SIMPRO REFERENCES:

Table 27 - Inventory data per functional unit (forest management) - SimaPro references (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Cork, raw {PT}| cork forestry | Cut-off, U	140.834,4	kg
Diesel, burned in building machine {GLO}| market for | Cut-off, U	13.055,07	MJ
Power sawing, without catalytic converter {RER}| processing | Cut-off, U	127,6783	hr
Transport, passenger car {RER}| market for | Cut-off, U	14,3778	km

Table 28 - Inventory data per functional unit (cork preparation) - SimaPro references (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Cork, raw {PT}| cork forestry | Cut-off, U	140.834,4	kg
Electricity, medium voltage {RER}| market group for | Cut-off, U	7.267,761	kWh
Natural gas, high pressure {Europe without Switzerland}| market group for | Cut-off, U	6.652,314	m^3
Water, unspecified natural origin, RER	676,0053	m^3
Transport, freight, lorry 16-32 metric ton, euro3 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO3 | Cut-off, U	7.794,481	tkm
Transport, freight, lorry 16-32 metric ton, euro3 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO3 | Cut-off, U	1.019,641	tkm
Transport, barge ship, bulk, 350t, 100%LF, default/GLO Economic	26,05437	tkm
Outputs:		
Cork planks	98.584,1	kg
Waste wood, untreated {RER}| market group for waste wood, untreated | Cut-off, U	42.250,33	kg
Sludge from pulp and paper production {Europe without Switzerland}| market for sludge from pulp and paper production | Cut-off, U	3.443,402	kg
Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, U	654,8801	m^3

Table 29 - Inventory data per functional unit (NCS production) - SimaPro references (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Electricity, high voltage {PT}| production mix | Cut-off, U	12.330,05	kWh
Lubricating oil {RoW}| market for lubricating oil | Cut-off, U	436,5867	L
Natural gas, high pressure {RoW}| natural gas production | Cut-off, U	7.485,35	m^3
Water, unspecified natural origin, PT	861,9067	m^3
Sodium hydroxide, production mix for PVC production, at plant, 100% NaOH RER	985,841	kg
Hydrogen peroxide, without water, in 50% solution state {RoW}| market for hydrogen peroxide, without water, in 50% solution state | Cut-off, U	2.366,018	kg
Sodium hydrogen sulfite {GLO}| market for | Cut-off, U	44,36285	kg
Citric acid {GLO}| market for | Cut-off, U	44,36285	kg
Enzymes {GLO}| market for enzymes | Cut-off, U	2,81669	kg
Coating powder {RER}| market for coating powder | Cut-off, U	1,22526	kg
Seal, natural rubber based {GLO}| market for | Cut-off, U	1,22526	kg
Sodium chloride, brine solution {GLO}| market for | Cut-off, U	24,64603	kg
Ethanol, without water, in 99.7% solution state, from fermentation, at service station {RoW}| market for | Cut-off, U	302,794	L
Ethylene glycol {RoW}| production | Cut-off, U Water, unspecified natural origin, PT	1.408,344	kg
Cork planks	98.584,1	kg
Transport, freight, lorry 16-32 metric ton, euro3 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO3 | Cut-off, U	24.783,76	tkm
Transport, barge ship, bulk, 350t, 100%LF, default/GLO Economic	630,9382	tkm
Outputs:		
NCS (unfinished)	29.575,23	kg
Waste wood, untreated {RER}| market group for waste wood, untreated | Cut-off, U	69.008,87	kg
Sludge from pulp and paper production {Europe without Switzerland}| market for sludge from pulp and paper production | Cut-off, U	313,3566	kg
Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, U	145,7636	m^3

Table 30 - Inventory data per functional unit (NCS finishing) - SimaPro references (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
NCS (unfinished)	29.575,23	kg
Electricity, high voltage {PT}| production mix | Cut-off, U	15.186,18	kWh
Acrylic varnish, without water, in 87.5% solution state {RER}| market for acrylic varnish, without water, in 87.5% solution state | Cut-off, U	3,52086	kg
Polydimethylsiloxane {GLO}| market for polydimethylsiloxane | Cut-off, U	84,50067	kg
Paraffin {GLO}| market for | Cut-off, U	415,4616	kg
Sulfur dioxide, liquid {RoW}| production | Cut-off, U	28,16689	kg
Outputs:		
NCS	28.166,89	kg
Waste wood, untreated {RER}| market group for waste wood, untreated | Cut-off, U	1408,345	kg

Table 31 - Inventory data per functional unit (NCS distribution) - SimaPro references (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Transport, barge ship, bulk, 350t, 100%LF, default/GLO Economic	122.720,886	tkm
Transport, freight, lorry 16-32 metric ton, euro4 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U	29.935,207	tkm
Transport, freight, lorry 16-32 metric ton, euro4 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U	18217,499	tkm
NCS	28.166,89	kg

- **OMNIPELLETS**

Table 32 - Inventory data per functional unit (pellet packaging) (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Pellets (produced)	434.782,6	kg
LDPE bags	0,155217388	kg
Outputs:		
Pellets (packed)	434.782,7552	kg

Table 33 - Inventory data per functional unit (pellet distribution) (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Transport (road)	396.521,7	tkm

Table 34 - Inventory data per functional unit (pellet usage) (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Pellets	434.782,6	kg
Electricity	35.252,64324	kWh
Outputs:		
CO	5.914.610,144	g
NOx	691.996,3303	g
SO2	86.825,95465	g
CH4 biogenic	55.751,40246	g
NMVOC	79.644,86066	g
Ashes to landfill	1.253.427,315	g
Energy	6.528.267,267	MJ

SIMPRO REFERENCES:

Table 35 - Inventory data per functional unit (pellet production) – SimaPro references (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Wood chips, dry, measured as dry mass {RER}| market for | Cut-off, U	434.782,6	kg
Electricity, high voltage {PT}| production mix | Cut-off, U	68.695.651	kWh
Diesel {Europe without Switzerland}| market for | Cut-off, U	373.913,04	kg
Wood chips, dry, measured as dry mass {RoW}| three layered laminated board production | Cut-off, U	86.956,52	kg
Outputs:		
Pellets (produced)	434.782,6	kg
Carbon monoxide	1.017,3913	kg
Carbon dioxide, fossil	1.186.956,5	kg
Nitrogen oxides, PT	134.347,82	kg
Sulfur dioxide, PT	17.391,304	kg
Methane, fossil	1.565,2174	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	24,04348	kg
Ash from paper production sludge {Europe without Switzerland}| treatment of ash from paper production sludge, residual material landfill | Cut-off, U	11.826,087	kg
Wood waste	86.956,52	kg

Table 36 - Inventory data per functional unit (pellet packaging) - SimaPro references (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Pellets (produced)	434.782,6	kg
Packaging film, low density polyethylene {GLO}| market for | Cut-off, U	0,155217388	kg
Outputs:		
Pellets (packed)	434.782,7552	kg

Table 37 - Inventory data per functional unit (pellet distribution) - SimaPro references (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Transport, freight, lorry 16-32 metric ton, euro3 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO3 | Cut-off, U	396.521,7	tkm

Table 38 - Inventory data per functional unit (pellet usage) - SimaPro references (E-LCA)

Inputs/outputs	Quantity	Unit
Inputs:		
Pellets	434.782,6	kg
Electricity, high voltage {PT}| production mix | Cut-off, U	35.252,64324	kWh
Outputs:		
Carbon monoxide	5.914.610,144	g
Nitrogen oxides, PT	691.996,3303	g
Sulfur dioxide, PT	86.825,95465	g
Methane, biogenic	55.751,40246	g
NMVOC, non-methane volatile organic compounds, unspecified origin	79.644,86066	g
Ash from paper production sludge {Europe without Switzerland}| treatment of ash from paper production sludge, residual material landfill | Cut-off, U	1.253.427,315	g
Energy	6.528.267,267	MJ

Appendix C

Results analysis

Table 39 - Comparison of the impact categories (between transportation scenarios) with percentages of decrease - NCS production process (E-LCA)

Impact category	Unit	Baseline scenario	Scenario 1	Scenario 2
GW	kg CO2 eq	1,224848	2%	4%
SOD	kg CFC11 eq	1,02E-06	1%	1%
IR	kBq Co-60 eq	0,008336	3%	4%
OF	kg NOx eq	0,004464	3%	4%

Table 39 - Comparison of the impact categories (between transportation scenarios) with percentages of decrease - NCS production process (E-LCA) (Continuation)

Impact category	Unit	Baseline scenario	Scenario 1	Scenario 2
FPMF	kg PM2.5 eq	0,001755	2%	3%
TA	kg SO2 eq	0,004598	2%	3%
FE	kg P eq	8,08E-05	0%	0%
ME	kg N eq	0,000328	0%	0%
TEco	kg 1,4-DCB	4,022183	14%	21%
FEco	kg 1,4-DCB	0,001975	5%	7%
MEco	kg 1,4-DCB	0,005751	7%	10%
HCT	kg 1,4-DCB	0,011788	0%	0%
HNCT	kg 1,4-DCB	0,286033	3%	5%
LU	m2a crop eq	22,55931	0%	0%
MRS	kg Cu eq	0,002046	1%	0%
FRS	kg oil eq	0,717703	2%	2%
WC	m3	0,042967	0%	0%

Table 40 - Comparison of the impact categories (between transportation scenarios) with percentages of decrease - Pellets distribution process (E-LCA)

Impact category	Unit	Baseline scenario	Scenario 1	Scenario 2
GW	kg CO2 eq	159079,8	17%	15%
SOD	kg CFC11 eq	0,086652	7%	6%
IR	kBq Co-60 eq	1454,616	16%	14%
OF	kg NOx eq	1705,771	8%	9%
FPMF	kg PM2.5 eq	370,4786	7%	7%
TA	kg SO2 eq	754,6786	7%	7%
FE	kg P eq	7,011551	0%	1%
ME	kg N eq	1,470962	4%	3%
TEco	kg 1,4-DCB	1227338	52%	42%
FEco	kg 1,4-DCB	214,8945	48%	39%
MEco	kg 1,4-DCB	914,9296	47%	38%
HCT	kg 1,4-DCB	1857,516	-4%[21]	-2%
HNCT	kg 1,4-DCB	36892,52	27%	22%
LU	m2a crop eq	209930,1	1%	0%
MRS	kg Cu eq	339,0175	-7%	-2%
FRS	kg oil eq	54934,47	19%	17%
WC	m3	2160,673	2%	2%

Table 41 - Comparison of the impact categories (between scenarios of wood chips amount) with percentages of decrease - Pellets production process (E-LCA)

Impact category	Unit	Baseline Scenario	Scenario 80%	Scenario 90%
GW	kg CO2 eq	93501,25	13%	7%
SOD	kg CFC11 eq	0,064408	17%	9%
IR	kBq Co-60 eq	931,1962	18%	9%
OF	kg NOx eq	788,6419	15%	7%
FPMF	kg PM2.5 eq	263,4063	15%	7%
TA	kg SO2 eq	501,563	13%	6%
FE	kg P eq	6,031677	14%	7%
ME	kg N eq	1,345424	14%	7%
TEco	kg 1,4-DCB	365348,5	18%	9%
FEco	kg 1,4-DCB	65,91612	17%	9%
MEco	kg 1,4-DCB	302,3736	17%	9%
HCT	kg 1,4-DCB	1483,494	18%	9%
HNCT	kg 1,4-DCB	22515,02	19%	9%
LU	m2a crop eq	207201,4	16%	8%
MRS	kg Cu eq	213,1992	17%	9%
FRS	kg oil eq	31816,48	15%	7%
WC	m3	1977,156	16%	8%

Appendix D

Social Life Cycle Assessment

LCI assumptions

1. Countries of origin (imports percentages)

Natural cork stoppers:

*Table 42 - Cork preparation stage in **Portugal** (import percentages and Atlas Code)*

Input										
Inventory	**Raw cork**	**%**	**Electricity**	**%**	**Natural gas**	**%**	**Water**	**%**	**Transport truck**	**%**
Atlas Code	450110		271600		271121		220110		2710	
Country | Imports percentage	Spain	64,63	Spain	100	Spain	100	Spain	62,81	Spain	48,2
Country | Imports percentage	Italy	29,59					Germany	12,14	Russia	11,41
Country | Imports percentage	USA	4,36					France	10,63	Belgium	11,26
Country | Imports percentage							UK	6,8	Netherlands	9,04
Country | Imports percentage							Italy	2,89	China	3,97
Country | Imports percentage							Belgium	1,56	Saudi Arabia	3,64
Country | Imports percentage							Luxembourg	1,21	France	2,24
Country | Imports percentage									Italy	1,74
Country | Imports percentage									Egypt	1,49
Country | Imports percentage									Brazil	1,34

[21] When the percentages are negative, it means that instead of a decrease in the impact category, there is in fact an increase.

*Table 43 - Cork preparation stage in **Algeria** (import percentages and Atlas Code)*

Input										
Inventory	**Raw cork**	**%**	**Electricity**	**%**	**Natural gas**	**%**	**Water**	**%**	**Transport truck**	**%**
Atlas Code	450110		27**		271121		2201***		2710	
Country | Imports percentage	Turkey	50,06	Italy	15,64	Singapore	100	Germany	77,06	Egypt	17,75
Country | Imports percentage	USA	49,94	Egypt	14,41			Czechia	22,94	France	16,43
Country | Imports percentage			France	13,44					Russia	14,09
Country | Imports percentage			Russia	11,59					Italy	14
Country | Imports percentage			Spain	8,83					USA	7,83
Country | Imports percentage			USA	6,36					Lithuania	6,96
Country | Imports percentage			Lithuania	5,67					Spain	6,36
Country | Imports percentage			Kazakhstan	4,68					Belgium	3,75
Country | Imports percentage			Netherlands	3,13					Netherlands	3,29
Country | Imports percentage			Belgium	3,06					Greece	2,48
Country | Imports percentage			Poland	2,6					Croatia	2,16
Country | Imports percentage			China	2,57					United Arab Emirates	1,45
Country | Imports percentage			Greece	2,03					Cyprus	1,2
Country | Imports percentage			Croatia	1,75						
Country | Imports percentage			United Arab Emirated	1,19						

*Table 44 - Cork preparation stage in **Morocco** (import percentages and Atlas Code)*

Input										
Inventory	**Raw cork**	**%**	**Electricity**	**%**	**Natural gas**	**%**	**Water**	**%**	**Transport truck**	**%**
Atlas Code	450110		271600		271121		220110		2710	
Country | Imports percentage	Spain	100	Spain	97,8	Algeria	100	Spain	78,27	Spain	26,49
Country | Imports percentage			Algeria	2,2			France	17,54	Saudi Arabia	10,87
Country | Imports percentage							Italy	2,15	Italy	10,68
Country | Imports percentage							Belgium	1,22	USA	10,26
Country | Imports percentage									Russia	9,01
Country | Imports percentage									Finland	6,02
Country | Imports percentage									Portugal	4,48
Country | Imports percentage									Undeclared	3,64
Country | Imports percentage									Netherlands	3,63
Country | Imports percentage									Sweden	3,24
Country | Imports percentage									Greece	2,03
Country | Imports percentage									Belgium	1,27
Country | Imports percentage									United Arab Emirates	1,27

Note: The value in red (in Table 44) that corresponds to "*Undeclared*" was not taken into consideration for future calculations and for the next steps; and that name ("*Undeclared*") is how the Atlas of Economic Complexity (Growth Lab of Harvard University, 2020) designated it.

*Table 45 - Cork preparation stage in **Spain** (import percentages and Atlas Code)*

Input												
Inventory	**Raw cork**	**%**	**Electricity**	**%**	**Natural gas**	**%**	**Water**	**%**	**Transport truck**	**%**	**Transport ship**	**%**
Atlas Code	450110		271600		271121		220110		2710		2710	
Country | Imports percentage	Portugal	82,58	France	67,5	Algeria	70,2	France	44,02	Italy	18,31	Italy	18,31
Country | Imports percentage	Italy	14,32	Portugal	31,38	France	17,59	Italy	21,9	Russia	10,45	Russia	10,45
Country | Imports percentage	France	2,75			Norway	9,81	UK	6,09	Saudi Arabia	8,28	Saudi Arabia	8,28
Country | Imports percentage					Morocco	2,22	Portugal	5,56	Portugal	7,77	Portugal	7,77
Country | Imports percentage							Croatia	5,55	France	5,45	France	5,45
Country | Imports percentage							Denmark	4,59	Netherlands	5,32	Netherlands	5,32
Country | Imports percentage							Belgium	4,21	Sweden	5,13	Sweden	5,13
Country | Imports percentage							Germany	2,77	Turkey	4,25	Turkey	4,25
Country | Imports percentage							Norway	1,42	USA	4,06	USA	4,06
Country | Imports percentage									Belgium	3,76	Belgium	3,76
Country | Imports percentage									Undeclared	3,6	Undeclared	3,6
Country | Imports percentage									UK	3,23	UK	3,23
Country | Imports percentage									Greece	2,3	Greece	2,3
Country | Imports percentage									Algeria	2,22	Algeria	2,22
Country | Imports percentage									Libya	2,11	Libya	2,11
Country | Imports percentage									India	1,97	India	1,97
Country | Imports percentage									Egypt	1,41	Egypt	1,41
Country | Imports percentage									Colombia	1,16	Colombia	1,16
Country | Imports percentage									United Arab Emirates	1,11	United Arab Emirates	1,11
Country | Imports percentage									Germany	1,1	Germany	1,1

Note: The values in red (in Table 45) that corresponds to "*Undeclared*" were not taken into consideration for future calculations and for the next steps.

Table 46 - Cork preparation stage in **Tunisia** (import percentages and Atlas Code)

Input										
Inventory	Raw cork	%	Electricity	%	Natural gas	%	Water	%	Transport truck	%
Atlas Code	450110		27**		2711***		2201		2710	
Country | Imports percentage	USA	100	Italy	36,75	France	32,77	Germany	41,44	Italy	39,55
Country | Imports percentage			Russia	12,12	Turkey	17,97	Norway	33,73	Russia	13,88
Country | Imports percentage			Egypt	9,9	Greece	16,25	Russia	24,83	Egypt	11,54
Country | Imports percentage			Greece	8,47	Italy	10,2			Greece	8,78
Country | Imports percentage			France	6,99	Romania	7,99			France	6,85
Country | Imports percentage			Azerbaijan	6,07	Russia	6,59			Portugal	5,59
Country | Imports percentage			Portugal	4,79	UK	5,88			Bulgaria	3,74
Country | Imports percentage			Bulgaria	3,21	Spain	2,19			Spain	2,01
Country | Imports percentage			Spain	2,92					Netherlands	1,7
Country | Imports percentage			Netherlands	1,51					Croatia	1,5
Country | Imports percentage			Croatia	1,29					Malta	1,25
Country | Imports percentage			Romania	1,1						
Country | Imports percentage			UK	1,07						
Country | Imports percentage			Malta	1,07						
Country | Imports percentage			USA	1						

Table 47 - Cork production stage in **Portugal** (import percentages and Atlas Code) – part 1

Input																
Inventory	Electricity	%	Lubricating oil	%	Natural gas	%	Water	%	NaOH	%	H2O2	%	NaHSO4	%	Citric Acid	%
Atlas Code	271600		340319		271121		220110		281511		284700		291529		291814	
Country | Imports percentage	Spain	100	Spain	55,38	Spain	100	Spain	62,81	Russia	21,3	Spain	48,36	South Korea	42,46	Austria	25
Country | Imports percentage			Germany	22,63			Germany	12,14	Spain	20,92	Netherlands	15,08	Spain	23,36	Belgium	20,64
Country | Imports percentage			France	6,33			France	10,63	Poland	16,33	Belgium	13,86	UK	20,98	China	20,49
Country | Imports percentage			Belgium	5,84			UK	6,8	France	11,3	United Kingdon	10,7	Germany	5,8	Spain	17,47
Country | Imports percentage			Netherlands	3,33			Italy	2,89	Belgium	9,87	Israel	8,05	Netherland:	2,86	Thailand	4,3
Country | Imports percentage			Italy	1,76			Belgium	1,56	Netherlands	5,79	France	3,54	France	2,12	Ireland	2,73
Country | Imports percentage			Lithuania	1,38			Luxembo	1,21	China	5,74			Italy	1,84	Germany	2,72
Country | Imports percentage									Kuwait	3,95					Sweden	1,93
Country | Imports percentage									United Kingdon	2,06					Italy	1,66
Country | Imports percentage									Taiwan	1,08					Netherland:	1,59
Country | Imports percentage									Sweden	1,02					France	1,08

Table 48 - Cork production stage in **Portugal** (import percentages and Atlas Code) – part 2

Input																
Inventory	Enzyme catalyst for H2O2	%	Antifouling mix	%	Anticorrosive	%	NaCl	%	Ethyl alcohol	%	Water based coverings	%	Transport truck	%	Transport ship	%
Atlas Code	381519		340520		340520		250100		220710		382000		2710		2710	
Country | Imports percentage	France	49,96	Spain	93,22	Spain	93,22	Netherlands	37,08	Spain	55,85	Spain	44,92	Spain	48,2	Spain	48,2
Country | Imports percentage	Sweden	23,99	Italy	1,24	Italy	1,24	Spain	28,82	Turkey	16,41	Germany	35,78	Russia	11,41	Russia	11,41
Country | Imports percentage	Japan	15,81					UK	21,21	France	13,6	Belgium	7,1	Belgium	11,26	Belgium	11,26
Country | Imports percentage	USA	4,38					Israel	4,09	Cyprus	11,62	UK	6,12	Netherlan	9,04	Netherlanc	9,04
Country | Imports percentage	Kuwait	2,91					France	3,01	Italy	1,63	Netherlands	2,32	China	3,97	China	3,97
Country | Imports percentage							Tunisia	2,13					Saudi Aral	3,64	Saudi Arab	3,64
Country | Imports percentage							Denmark	1,07					France	2,24	France	2,24
Country | Imports percentage													Italy	1,74	Italy	1,74
Country | Imports percentage													Egypt	1,49	Egypt	1,49
Country | Imports percentage													Brazil	1,34	Brazil	1,34

*Table 49 - Cork finishing stage in **Portugal** (import percentages and Atlas Code)*

Input										
Inventory	Electricity	%	Paint	%	Silicone oil	%	Paraffin	%	SO2	%
Atlas Code	271600		321000		340319		271220		2811	
Country | Imports percentage	Spain	100	Spain	40,3	Spain	55,38	Spain	34,16	Spain	48,57
Country | Imports percentage			Germany	27,92	Germany	22,63	China	18,65	France	30,74
Country | Imports percentage			Italy	24,43	France	6,33	South Africa	14,99	Germany	5,55
Country | Imports percentage			France	1,69	Belgium	5,84	Malaysia	12,44	India	4,9
Country | Imports percentage			UK	1,29	Netherlands	3,33	Germany	8,21	Italy	4,5
Country | Imports percentage			Netherlands	1,12	Italy	1,76	Belgium	3,08	Netherlan	1,85
Country | Imports percentage					Lithuania	1,38	India	1,99	China	1,07
Country | Imports percentage							Netherlands	1,65		
Country | Imports percentage							Italy	1,11		
Country | Imports percentage										

*Table 50 - Cork distribution stage from **Portugal** (import percentages and Atlas Code)*

Input				
Inventory	Transport truck	%	Transport ship	%
Atlas Code	2710		2710	
Country | Imports percentage	Spain	48,2	Spain	48,2
Country | Imports percentage	Russia	11,41	Russia	11,41
Country | Imports percentage	Belgium	11,26	Belgium	11,26
Country | Imports percentage	Netherlands	9,04	Netherlands	9,04
Country | Imports percentage	China	3,97	China	3,97
Country | Imports percentage	Saudi Arabia	3,64	Saudi Arabia	3,64
Country | Imports percentage	France	2,24	France	2,24
Country | Imports percentage	Italy	1,74	Italy	1,74
Country | Imports percentage	Egypt	1,49	Egypt	1,49
Country | Imports percentage	Brazil	1,34	Brazil	1,34

Pellets:

*Table 51 - Pellets production stage in **Portugal** (import percentages and Atlas Code)*

Input								
Inventory	Wood chips	%	Electricity	%	Diesel	%	Sawdust	%
Atlas Code	440121		271600		2710		1	
Country | Imports percentage	Spain	99,62	Spain	100	Spain	48,2	Spain	83,98
Country | Imports percentage					Russia	11,41	France	5,1
Country | Imports percentage					Belgium	11,26	Germany	4,06
Country | Imports percentage					Netherlands	9,04	Belgium	1,96
Country | Imports percentage					China	3,97	Netherlands	1,71
Country | Imports percentage					Saudi Arabia	3,64	Estonia	1,11
Country | Imports percentage					France	2,24		
Country | Imports percentage					Italy	1,74		
Country | Imports percentage					Egypt	1,49		
Country | Imports percentage					Brazil	1,34		

*Table 52 - Pellets packaging stage in **Portugal** (import percentages and Atlas Code)*

Input		
Inventory	LDPE bags	%
Atlas Code	392321	
Country | Imports percentage	Spain	52,85
Country | Imports percentage	Germany	9,9
Country | Imports percentage	Netherlands	8,1
Country | Imports percentage	Italy	6,33
Country | Imports percentage	Belgium	4,99
Country | Imports percentage	Vietnam	3,96
Country | Imports percentage	China	2,79
Country | Imports percentage	France	2,63
Country | Imports percentage	UK	2,45
Country | Imports percentage	India	1,35
Country | Imports percentage	Malaysia	1

*Table 53 - Pellets usage stage in **Portugal** (import percentages and Atlas Code)*

Input		
Inventory	Electricity	%
Atlas Code	271600	
Country | Imports percentage	Spain	100

*Table 54 - Pellets distribution stage in **Portugal** (import percentages and Atlas Code)*

Input		
Inventory	Transport truck	%
Atlas Code	2710	
Country | Imports percentage	Egypt	17,75
Country | Imports percentage	France	16,43
Country | Imports percentage	Russia	14,09
Country | Imports percentage	Italy	14
Country | Imports percentage	USA	7,83
Country | Imports percentage	Lithuania	6,96
Country | Imports percentage	Spain	6,36
Country | Imports percentage	Belgium	3,75
Country | Imports percentage	Netherlands	3,29
Country | Imports percentage	Greece	2,48
Country | Imports percentage	Croatia	2,16
Country | Imports percentage	United Arab Emirates	1,45
Country | Imports percentage	Cyprus	1,2

2. Prices (and respective references and date of access)

It is important to note that the conversion from all currencies used in this section (EUR, MAD, DZD, TND, etc.) to USD was done resorting to Morningstar (2020) on 24th of August 2020. In the same day, the conversion from USD to USD of 2011 was performed using the tool developed by Webster (2020).

Natural cork stoppers:

*Table 55 - Cork preparation stage in **Portugal** (prices and references)*

Material	Price (unit)	Reference	Notes
Raw cork	1,846 €/kg	(ICNF, 2018)	Report by ICNF – *Instituto da Conservação da Natureza e das Florestas**
Electricity	0,15252 €/kWh	(Selectra, 2020a)	The value considers the main electricity distributors in Portugal and makes the average of their values.
Natural gas	0,05892 €/kWh	(Selectra, 2020a)	The value considers the main natural gas distributors in Portugal and makes the average of their values.
Water	1,6281 €/m^3	(Águas de Santarém, 2020)	From the table of prices found on the website, the price used was the one for *Não domésticos* (non-domestic); and it was *Águas* (waters) of Santarém because one of the factory of Corticeira Amorim is located in Coruche, which belongs to Santarém district.
Diesel	1,228 €/L	(DGEG, 2020)	Information by DGEG – *Direção-Geral de Energia e Geologia*; The price is the average price of the simple diesel on 12/7/2020 in Portugal (with the information of 2392 gas stations)

* The report *Síntese Económica* 2018 (Economic Summary 2018) by ICNF had information regarding cork's price in the Excel's tab *Cotações de cortiça*, like Table 56 shows:

Table 56 - Raw cork price in 2017 (according to a report by ICNF)

	Cortiça Amadia (EUR/Arroba)	Alentejo	Ribatejo e Oeste	Trás-os montes	Nacional
2017	Mínimo	15,00	25,00	20,00	15,00
	Média	29,13	30,05	23,89	
	Mediana	28,00	30,00	25,00	
	Máximo	44,00	30,00	27,50	44,00

The raw cork price per kg was obtained by doing the average of the three values in yellow (which are the average values of each one of those cork oak forests locations in year 2017). Besides that, the price there appears in euros per *arroba*, which is a unit used mainly in the cork production business and is the equivalent of 15 kg.

*Table 57 - Cork preparation stage in **Spain** (prices and references)*

Material	Price (unit)	Reference	Notes
Raw cork	1,85 €/kg	(Agro Popular, 2017)	*"…los precios se encuentran entre los 50 y los 120 euros el quintal castellano (46 kilos)…"* *
Electricity	0,09377 €/kWh	(Selectra, 2020c)	Average price of all the electricity values throughout the day
Natural gas	0,04785 €/kWh	(Selectra, 2020b)	"*…el precio estará entre los **0,045** y **0,0507** €/kWh*" – it was calculated the average price between those two
Water	1,84 €/m^3	(Medialdea, 2020)	The reference is an article of the ABC newspaper that says that according to the *Asociación Española de Abastecimiento de Agua y Saneamiento*, that price is the average one in Spain.
Diesel	1,159 €/L	(DieseloGasolina, 2020)	Average price for all types of diesel in the day of research; The information on the website was based on information by the *Ministerio de Industria, Energía y Turismo*.
Bunker oil	1,21 USD/gallon	(IndexMundi, 2020a)	Price on the day of research; the prices of fuel oil are highly unstable

* Regarding the information available on the website mentioned for the raw cork price information, the sentence in the column *Notes* means that the prices of raw cork vary between 50 and 120 euros per 46 kg. Then, the average between the two values was calculated ((50+120)/2 = 85 €); and then it was just dividing that value per 46kg and that is how the 1,85 €/kg was obtained.

*Table 58 - Cork preparation stage in **Morocco** (prices and references)*

Material	Price (unit)	Reference	Notes
Raw cork	1,668 €/kg	(ICNF, 2018)	
Electricity	1,072 MAD[22]/kWh	(GlobalPetrolPrices, 2020d)	Information from Morocco, December 2019; Electricity price for business and the price includes the cost of power, distribution, and taxes
Natural gas	0,0065 $/kWh	(Al-Arab Al-Youm Media, 2020)	The price of natural gas in Morocco, January 2020; The price in the newspaper article appears in mmBTU (1,91 mmBTU); the convertion of units is 1mmBTU = 293,07kWh (took from (Calc Hub, 2020))
Water	1,52 USD/m^3	(Favre & Montginoul, 2018)	One can read in the article, the title of Table 2 "*Tariff and incentives to water conservation (from tariff schedule in force in 2016, including water and sewerage*", where it displays the value for Morocco, Casablanca (1,52 $/m^3)
Diesel	8,24 MAD/L	(GlobalPetrolPrices, 2020c)	Price for diesel in Morocco on 10/8/2020

*Table 59 - Cork preparation stage in **Algeria** (prices and references)*

Material	Price (unit)	Reference	Notes
Raw cork	1,668 €/kg	(ICNF, 2018)	
Electricity	4,472 DZD[23]/kWh	(Algérie Électricité, 2020)	-
Natural gas	0,476 DZD/kWh	(GlobalPetrolPrices, 2020b)	Info from Algeria of March 2020
Water	0,32 USD/m^3	(Favre & Montginoul, 2018)	The price for Algeria, Alger, Oran, Constantine also appears in Table 2 of the article referenced
Diesel	27,63 DZD/L	(GlobalPetrolPrices, 2020a)	"*We show prices for Algeria from 27-Apr-2020 to 03-Aug-2020. The average value for Algeria during that period was 27.63*"

*Table 60 - Cork preparation stage in **Tunisia** (prices and references)*

Material	Price (unit)	Reference	Notes
Raw cork	1658 TND[24]/ton	(Zidi & Daly, 2019)	Information took from a Report by *Observatoire National de l'Agriculture Tunisie*; and the information is in page 28 in the first table under *"Liège naturel brut"* (raw cork), column of "*Prix*" (price)
Electricity	0,302 TND/kWh	(GlobalPetrolPrices, 2020e)	Price information from Tunisia, June 2020
Natural gas	300,59 *milliemes*[25]/kWh	(STEG, 2020)	STEG - *Société Tunisienne de l'Électricité et du Gaz*; Average price of the non-residencial values and it was added 19% of taxes on top of that; Conversion currency (from milliemes to €): (Ostermiller, 2020)
Water	0,61 USD/m^3	(Favre & Montginoul, 2018)	The price appears in Table 2 of the article and it is the price for the national operator's centres in Tunisia, it includes price for the water and the sewerage
Diesel	2 TND/L	(GlobalPetrolPrices, 2020f)	"*We show prices for Tunisia from 27-Apr-2020 to 03-Aug-2020. The average value for Tunisia during that period was 2.00 Tunisian Dinar*"

*Table 60 - Cork preparation stage in **Tunisia** (prices and references) (Continuation)*

[22] MAD = Moroccan Dirham
[23] DZD = Algerian Dinar
[24] TND = Tunisian Dinar
[25] The Egyptian pound is divided into 100 *piasters* or 1000 *milliemes*.

*Table 61 - Cork production stage in **Portugal** (prices and references)*

Material	Price (unit)	Reference	Notes
Electricity	0,15252 €/kWh	(Selectra, 2020a)	Explained in Table 55
Water	1,6281 €/m^3	(Águas de Santarém, 2020)	Explained in Table 55
Natural gas	0,05892 €/kWh	(Selectra, 2020a)	Explained in Table 55
Lubricating oil	7,68 € for a 500mL container	(OLX, 2020)	-
NaOH	3,95 €/kg	(Restaurar&Conservar, 2020)	-
H_2O_2	9,34 € for a 16 fl. container	(LuckyVitamin LLC., 2020)	-
$NaHSO_4$	136,17 € for a bag of 25kg	(Loja dos Químicos, 2020)	The information of the price was provided by e-mail; This price already includes the transport
Citric Acid	2,75 € for a 100g container	(Cenários Gulosos, 2020)	-
Enzyme catalyst for H_2O_2	7,38 € for a 20mL container	(Grupo Vitalino, 2020)	-
Antifouling mix	115,77 € for a 2,5 L container	(DND, 2020)	-
Anticorrosive	8,49 € for a 0,25L container	(Leroy Merlin, 2020)	-
NaCl	22,7 € for a 100mL container	(Hach, 2020)	-
Ethyl alcohol	1,28 € for a 0,25L container	(MIPMED, 2020)	-
Water based coverings	8,78 €/L	(CYPE Ingenieros, 2020)	-
Diesel	1,228 €/L	(DGEG, 2020)	Explained in Table 55
Bunker oil	1,19 €/gallon	(IndexMundi, 2020b)	Price on the day of research; the prices of bunker oil are highly unstable

*Table 62 - Cork finishing stage in **Portugal** (prices and references)*

Material	Price (unit)	Reference	Notes
Electricity	0,15252 €/kWh	(Selectra, 2020a)	Explained in Table 55
Paint	137,76 € for a 500mL container	(Fabriprint, 2020)	-
Silicone oil	5,7 € for a 50mL container	(RTR Modelismo, 2020)	-
Paraffin	43,67 € for a 5kg bar	(LojaPro, 2020)	-
SO_2	2,48 €/kg	(Linde Portugal, 2020)	Information provided by e-mail; for quantities up to 600kg the price per kg is 2,7+IVA; for a purchase of more than that, the price can lower to 2€+IVA per kg (IVA is 24%). The second approach was the one assumed to be used by Corticeira Amorim

*Table 63 - Cork distribution stage from **Portugal** (prices and references)*

Material	Price (unit)	Reference	Notes
Diesel	1,228 €/L	(DGEG, 2020)	Explained in Table 55
Bunker oil	1,19 €/gallon	(IndexMundi, 2020b)	Price on the day of research; the prices of bunker oil are highly unstable

Pellets:

*Table 64 - Pellets production stage in **Portugal** (prices and references)*

Material	Price (unit)	Reference	Notes
Wood chips	12,19 € for a 20kg bag	(Miscota, 2020)	-
Electricity	0,15252 €/kWh	(Selectra, 2020a)	Explained in Table 55
Diesel	1,228 €/L	(DGEG, 2020)	Explained in Table 55
Sawdust	50 €/ton	(Grazimadeiras, 2020)	The price information was provided by e-mail

*Table 65 - Pellets packaging stage in **Portugal** (prices and references)*

Material	Price (unit)	Reference	Notes
LDPE bags	6,94 €/kg	(Inapa packaging, 2020)	-

*Table 66 - Pellets distribution stage in **Portugal** (prices and references)*

Material	Price (unit)	Reference	Notes
Diesel	1,228 €/L	(DGEG, 2020)	Explained in Table 55

*Table 67 - Pellets usage stage in **Portugal** (prices and references)*

Material	Price (unit)	Reference	Notes
Electricity	0,15252 €/kWh	(Selectra, 2020a)	Explained in Table 55

3. Domestic production (percentage of production that is done by the own country; and respective reference)

Natural Cork Stoppers:

*Table 68 - Cork preparation stage in **Portugal** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Raw cork	53,61%	1) (Jorge Sierra-Pérez & Durany, 2015) 2) (ICNF, 2018)*	1) "*…the extraction of Portuguese raw cork only represents 53% of the national production needs…*" (from Reference 1, which corroborates the calculations made with the help of Reference 2 and its information); 2) Reference 2 involved calculation, so the detailed explanation is below
Electricity	83%	1) (IEA, 2016) 2) (IndexMundi, 2020c)	IEA is the International Energy Agency
Natural gas	0%	1) (IEA, 2016) 2) (IndexMundi, 2019c)	1) "*Portugal has no fossil fuel production (including coal, oil and **natural gas**).*"

*Table 68 - Cork preparation stage in **Portugal** (domestic production and references) (Continuation)*

			2) The second reference confirms the fact above and affirms that Portugal produces 0 cubic meters of natural gas.
Water	100%	(Águas de Portugal, 2019)	-
Diesel	0%	(IEA, 2016)	1) "*Portugal has no fossil fuel production (including **coal**, oil and natural gas).*" 2) The second reference corroborates the fact that Portugal does not produce diesel.

Table 69 - Imports, exports and production of raw cork in 2017 (ICNF, 2018)

Year 2017	Amount of raw cork (kg)
Imports	49.178.079
Exports	7.986.774
Produced	64.819.006
Total quantity	106.010.311

*Table 70 - Cork preparation stage in **Spain** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Raw cork	57%	(Jorge Sierra-Pérez & Durany, 2015)	The percentage of the domestic production was found by discovering the percentage of imports: %imp= I/(P+I) = 46526/108030 = 43% So, the domestic production is 100-43=57%
Electricity	89%	1) (IEA, 2015) 2) (IndexMundi, 2019a)	1) "*In 2014, Spain's cross-border electricity trade amounted to 28 TWh, corresponding to around **11%** of electricity demand in the country*. " – if Spain imports 11% of its electricity, then the remaining 89% is domestic production; 2) This reference reinforces the numbers above
Natural gas	26%	(EIA, 2017)	"*In 2016, Algeria supplied about **52%** of Spain's total natural gas...*" With the percentage of imports coming from Algeria (of the total amount of natural gas used in Spain) – 52% –, and with the percentages in Table 45 (saying that Algeria represents 70,2% of the total of imports), it was a matter of calculating the other percentages of imports from other countries, and then getting the remaining as the domestic production
Water	100%	-	-
Diesel	1%	(IEA, 2015)	-
Bunker oil	1%	(IEA, 2015)	-

*Table 71 - Cork preparation stage in **Morocco** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Raw cork	95%	1) (APCOR, 2015a) 2) (Jorge Sierra-Pérez & Durany, 2015)	1) This reference has the amount of raw cork produced in Morocco; 2) Contains data regarding the imports from Spain (which is the only country from where Morocco imports from)
Electricity	84,39%	1) (WLPGA, 2015) 2) (IndexMundi, 2019b)	1) WLPGA is the World LPG (Liquefied petroleum gas) Association; "*large quantities of electricity are imported from Spain (~15%)*" 2) This reference provides the amount of electricity produced, the amount of electricity actually used, and the imports and exports of electricity; Doing the calculations and with the information of Reference 1 (that matches the values obtained here), the value 84,39% was obtained
Natural gas	7%	1) (WLPGA, 2015) 2) (IndexMundi, 2019b)	1) "*The vast majority of its **natural gas** is imported from Algeria (a mere 7% sourced from domestic production)*" 2) This reference has the produced and used amount of natural gas, as well as the imports and exports; doing the calculations, the results match the 7% of Reference 1
Water	100%	-	-
Diesel	0,26%	(IndexMundi, 2019b)	The reference has the values of the imports, exports and amount of diesel produced in Morocco. One more time, the calculations were performed to obtain the value displayed here.

*Table 72 - Cork preparation stage in **Algeria** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Raw cork	95%	(FAO, 2015)	FAO is the Food and Agriculture Organization of the United Nations
Electricity	99,5%	(CIA, 2020)	CIA is the Central Intelligence Agency; and the reference is the World Factbook, which for Algeria has the values of electricity production, consumption, imports, and exports (in kWh). By doing the calculations of the percentage of domestic production, the value 99,5% was obtained
Natural gas	100%	(CIA, 2020)	Algeria imports 0% of its natural gas
Water	100%	-	-
Diesel	80%	(CIA, 2020)	This reference has the values of the production, consumption, imports, and exports of "*Refined petroleum products*"; it was also a matter of calculating the percentage of domestic production

*Table 73 - Cork preparation stage in **Tunisia** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Raw cork	99,96%	1) (Cork Quality Council, 2017) 2) (Growth Lab of Harvard University, 2020) 3) (Brooks, 1997)	1) The first reference contains the information regarding the amount of raw cork produced by Tunisia; 2) The second one has the information about the imports and exports of raw cork; 3) This last one has information regarding the price of raw cork in the USA – since this is the only country from where Tunisia imports raw cork from; With all this information combined, one was able to obtain the value of the domestic production percentage

*Table 73 - Cork preparation stage in **Tunisia** (domestic production and references) (Continuation)*

Electricity	99,26%	(IndexMundi, 2019d)	This reference provides the production, consumption, imports, and exports of electricity; To obtain the value 99,26%, it was a matter of calculations; Then, with the final values of the electricity share, ten countries revealed a percentage lower then 0,05%. Hence, they were eliminated from further considerations.
Natural gas	75,14%	(IndexMundi, 2019d)	This reference provides the production, consumption, imports, and exports of natural gas; Then, it was a matter of calculations to obtain the value
Water	100%	-	-
Diesel	31%	(IndexMundi, 2019d)	This reference provides the production, consumption, imports, and exports of diesel; Then, it was a matter of calculations to obtain this percentage

*Table 74 - Cork production stage in **Portugal** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Electricity	83%	-	Explained in Table 68
Water	100%	-	-
Natural gas	0%	-	Explained in Table 68
Lubricating oil	12,92%	(CEFIC, 2020)	CEFIC is the European Chemical Industry Council; See the graphic on page 12 of the report; assuming that Portugal follows the trend of the European Union and produces 12,92% of its products of the chemical industry
NaOH	12,92%	(CEFIC, 2020)	Chemical industry - the assumptions are the same as the ones for the lubricating oil (for this product and all the others that were considered to be part of the chemical industry)
H_2O_2	12,92%	(CEFIC, 2020)	Chemical industry
$NaHSO_4$	12,92%	(CEFIC, 2020)	Chemical industry
Citric Acid	12,92%	(CEFIC, 2020)	Chemical industry
Enzyme catalyst for H_2O_2	12,92%	(CEFIC, 2020)	Chemical industry
Antifouling mix	12,92%	(CEFIC, 2020)	Chemical industry
Anticorrosive	12,92%	(CEFIC, 2020)	Chemical industry
NaCl	12,92%	(CEFIC, 2020)	Chemical industry
Ethyl alcohol	12,92%	(CEFIC, 2020)	Chemical industry
Water based coverings	12,92%	(CEFIC, 2020)	Chemical industry
Diesel	0%	-	Explained in Table 68
Bunker oil	0%	(IEA, 2016)	*"Portugal has no fossil fuel production (including coal, oil and natural gas)."*

*Table 75 - Cork finishing stage in **Portugal** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Electricity	83%	-	Explained in Table 68
Paint	12,92%	(CEFIC, 2020)	Chemical industry (explained in Table 74)
Silicone oil	12,92%	(CEFIC, 2020)	Chemical industry
Paraffin	12,92%	(CEFIC, 2020)	Chemical industry
SO_2	12,92%	(CEFIC, 2020)	Chemical industry

*Table 76 - Cork distribution stage from **Portugal** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Diesel	0%	-	Explained in Table 68
Bunker oil	0%	-	Explained in Table 74

Pellets:

*Table 77 - Pellets production stage in **Portugal** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Wood chips	32,6%	(ICNF, 2018)	Explained below
Electricity	83%	-	Explained in Table 68
Diesel	0%	-	Explained in Table 68
Sawdust	75,34%	(ICNF, 2018)	Explained below

*Table 78 - Pellets packaging stage in **Portugal** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
LDPE bags	12,92%	(CEFIC, 2020)	Chemical industry

*Table 79 - Pellets distribution stage in **Portugal** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Diesel	0%	-	Explained in Table 68

*Table 80 - Pellets usage stage in **Portugal** (domestic production and references)*

Material	Domestic production (percentage)	Reference	Notes
Electricity	83%	-	Explained in Table 68

Natural cork stoppers:

*Table 81 - LCI of the **cork preparation** stage in **Spain**, for Corticeira Amorim (S-LCA)*

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
Raw cork	1,89514 USD2011 per kg	FRS	Spain	57%
			Portugal	35,51%
			Italy	6,16%
			France	1,18%
Electricity	0,096058 USD2011 per kWh	ELY	Spain	89%
			France	7,43%
			Portugal	3,45%
Natural gas	0,049018 USD2011 per kWh	GAS	Spain	26%
			Algeria	52%
			France	13,03%
			Norway	7,27%
			Morocco	1,64%
Water	1,884896 USD2011 per m^3	WTR	Spain	100%
Road transport (diesel)	1,18728 USD2011 per L	OTP	Spain	1%
			Italy	18,13%
			Russia	10,35%
			Saudi Arabia	8,20%
			Portugal	7,69%
			France	5,40%
			Netherlands	5,27%
			Sweden	5,08%
			Turkey	4,21%
			USA	4,02%
			Belgium	3,72%
			UK	3,20%
			Greece	2,28%
			Algeria	2,20%
			Libya	2,09%
			India	1,95%
			Egypt	1,40%
			Colombia	1,15%
			United Arab Emirates	1,10%
			Germany	1,09%
Sea transport (bunker oil)	1,239524 USD2011 per gallon	WTP	Spain	1%
			Italy	18,13%
			Russia	10,35%
			Saudi Arabia	8,20%
			Portugal	7,69%
			France	5,40%
			Netherlands	5,27%
			Sweden	5,08%
			Turkey	4,21%
			USA	4,02%
			Belgium	3,72%
			UK	3,20%
			Greece	2,28%
			Algeria	2,20%
			Libya	2,09%
			India	1,95%
			Egypt	1,40%
			Colombia	1,15%
			United Arab Emirates	1,10%
			Germany	1,09%

*Table 82 - LCI of the **cork preparation** stage in **Morocco**, for Corticeira Amorim (S-LCA)*

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
Raw cork	1,710748 USD2011 per kg	FRS	Morocco	95%
			Spain	5%
Electricity	0,101421 USD2011 per kWh	ELY	Morocco	84,39%
			Spain	15,27%
			Algeria	0,34%
Natural gas	0,005652 USD2011 per kWh	GAS	Morocco	7%
			Algeria	93%
Water	1,321739 USD2011 per m^3	WTR	Morocco	100%
Road transport (diesel)	0,779576 USD2011 per L	OTP	Morocco	0,26%
			Spain	26,42%
			Saudi Arabia	10,84%
			Italy	10,65%
			USA	10,23%
			Russia	8,99%
			Finland	6%
			Portugal	4,47%
			Netherlands	3,62%
			Sweden	3,23%
			Greece	2,02%
			Belgium	1,27%
			United Arab Emirates	1,27%

Table 83 - LCI of the ***cork preparation*** *stage in* ***Tunisia****, for Corticeira Amorim (S-LCA)*

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
Raw cork	0,528591 USD2011 per kg	FRS	Tunisia	99,96%
Electricity	0,097165 USD2011 per kWh	ELY	Tunisia	99,26%
			Italy	0,27%
			Russia	0,09%
			Egypt	0,07%
			Greece	0,06%
			France	0,05%
Natural gas	0,01639 USD2011 per kWh	GAS	Tunisia	75,14%
			France	8,15%
			Turkey	4,47%
			Greece	4,04%
			Italy	2,54%
			Romania	1,99%
			Russia	1,64%
			UK	1,46%
			Spain	0,54%
Water	0,530435 USD2011 per m^3	WTR	Tunisia	100%
Road transport (diesel)	0,643478 USD2011 per L	OTP	Tunisia	31%
			Italy	27,29%
			Russia	9,58%
			Egypt	7,96%
			Greece	6,06%
			France	4,73%
			Portugal	3,86%
			Bulgaria	2,58%
			Spain	1,39%
			Netherlands	1,17%
			Croatia	1,04%
			Malta	0,86%

Table 84 - LCI of the ***cork preparation*** *stage in* ***Algeria****, for Corticeira Amorim (S-LCA)*

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
Raw cork	1,710748 USD2011 per kg	FRS	Algeria	95%
			Turkey	3%
			USA	2%
Electricity	0,03033 USD2011 per kWh	ELY	Algeria	99,5%
			Italy	0,08%
			Egypt	0,07%
			France	0,07%
			Russia	0,06%
Natural gas	0,003217 USD2011 per kWh	GAS	Algeria	100%
Water	0,278261 USD2011 per m^3	WTR	Algeria	100%
Road transport (diesel)	0,187403 USD2011 per L	OTP	Algeria	80%
			Egypt	3,55%
			France	3,29%
			Russia	2,82%
			Italy	2,80%
			USA	1,57%
			Lithuania	1,39%
			Spain	1,27%
			Belgium	0,75%
			Netherlands	0,66%
			Greece	0,50%
			Croatia	0,43%
			United Arab Emirates	0,29%
			Cyprus	0,24%

Table 85 - LCI of the ***NCS production*** *stage in* ***Portugal****, for Corticeira Amorim (S-LCA)*

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
Electricity	0,156241 USD2011 per kWh	ELY	Portugal	83%
			Spain	17%
Lubricating oil	15,73478 USD2011 per L	OIL	Portugal	12,92%
			Spain	48,22%
			Germany	19,71%
			France	5,51%
			Belgium	5,09%
			Netherlands	2,90%
			Italy	1,53%
			Lithuania	1,20%
Natural gas	0,060358 USD2011 per kWh	GAS	Spain	100%
Water	1,667826 USD2011 per m^3	WTR	Portugal	100%
NaOH	4,04638 USD2011 per kg	CRP	Portugal	12,92%
			Russia	18,55%
			Spain	18,22%
			Poland	14,22%
			France	9,84%
			Belgium	8,59%
			Netherlands	5,04%
			China	5,00%
			Kuwait	3,44%
			UK	1,79%
			Taiwan	0,94%
			Sweden	0,89%
H_2O_2	20,22166 USD2011 per kg	CRP	Portugal	12,92%
			Spain	42,11%
			Netherlands	13,13%
			Belgium	12,07%
			UK	9,32%
			Israel	7,01%
			France	3,08%
$NaHSO_4$	5,579702 USD2011 per kg	CRP	Portugal	12,92%
			South Korea	36,97%
			Spain	20,34%
			UK	18,27%
			Germany	5,05%
			Netherlands	2,49%
			France	1,85%

Table 86 - LCI of the ***NCS finishing*** *stage in* ***Portugal****, for Corticeira Amorim (S-LCA)*

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
Electricity	0,156241 USD2011 per kWh	ELY	Portugal	83%
			Spain	17%
Paint	282,2427 USD2011 per L	CRP	Portugal	12,92%
			Spain	35,09%
			Germany	24,31%
			Italy	21,27%
			France	1,47%
			UK	1,12%
			Netherlands	0,98%
Silicone oil	116,7816 USD2011 per L	CRP	Portugal	12,92%
			Spain	48,22%
			Germany	19,71%
			France	5,51%
			Belgium	5,09%
			Netherlands	2,90%
			Italy	1,53%
			Lithuania	1,20%
Paraffin	8,94711 USD2011 per kg	CRP	Portugal	12,92%
			Spain	29,75%
			China	16,24%
			South Africa	13, 05%
			Malaysia	10,83%
			Germany	7,15%
			Belgium	2,68%
			India	1,73%
			Netherlands	1,44%
			Italy	0,97%
SO_2	2,540512 USD2011 per kg	CRP	Portugal	12,92%
			Spain	42,29%
			France	26,77%
			Germany	4,83%
			India	4,27%
			Italy	3,92%
			Netherlands	1,61%
			China	0,93%

*Table 85 - LCI of the **NCS production** stage in **Portugal**, for Corticeira Amorim (S-LCA) (Continuation)*

			Italy	1,60%
Citric acid	28,171 USD2011 per kg	CRP	Portugal	12,92%
			Austria	21,77%
			Belgium	17,97%
			China	17,84%
			Spain	15,21%
			Thailand	3,74%
			Ireland	2,38%
			Germany	2,27%
			Sweden	1,68%
			Italy	1,45%
			Netherlands	1,38%
			France	0,94%
Enzyme catalyst for H_2O_2	378,0036 USD2011 per L	CRP	Portugal	12,92%
			France	43,51%
			Sweden	20,89%
			Japan	13,77%
			USA	3,81%
			Kuwait	2,53%
Antifouling mix	47,43792 USD2011 per L	CRP	Portugal	12,92%
			Spain	81,18%
			Italy	1,08%
Anticorrosive	34,78862 USD2011 per L	CRP	Portugal	12,92%
			Spain	81,18%
			Italy	1,08%
NaCl	232,5388 USD2011 per L	CRP	Portugal	12,92%
			Netherlands	32,29%
			Spain	25,10%
			UK	18,47%
			Israel	3,56%
			France	2,62%
			Tunisia	1,85%
			Denmark	0,93%
Ethyl alcohol	5,244928 USD2011 per L	CRP	Portugal	12,92%
			Spain	48,63%
			Turkey	14,29%
			France	11,84%
			Cyprus	10,12%
			Italy	1,42%
Water based coverings	8,994232 USD2011 per L	CRP	Portugal	12,92%
			Spain	39,12%
			Germany	31,16%
			Belgium	6,18%
			UK	5,33%
			Netherlands	2,02%
Road transport (diesel)	1,257963 USD2011 per L	OTP	Spain	48,2%
			Russia	11,41%
			Belgium	11,26%
			Netherlands	9,04%
			China	3,97%
			Saudi Arabia	3,64%
			France	2,24%
			Italy	1,74%
			Egypt	1,49%
			Brazil	1,34%
Sea transport (bunker oil)	1,034783 USD2011 per gallon	WTP	Spain	48,2%
			Russia	11,41%
			Belgium	11,26%
			Netherlands	9,04%
			China	3,97%
			Saudi Arabia	3,64%
			France	2,24%
			Italy	1,74%
			Egypt	1,49%
			Brazil	1,34%

*Table 87 - LCI of the **NCS distribution** stage from **Portugal**, for Corticeira Amorim (S-LCA)*

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
Road transport (diesel)	1,257963 USD2011 per L	OTP	Spain	48,2%
			Russia	11,41%
			Belgium	11,26%
			Netherlands	9,04%
			China	3,97%
			Saudi Arabia	3,64%
			France	2,24%
			Italy	1,74%
			Egypt	1,49%
			Brazil	1,34%
Sea transport (bunker oil)	1,034783 USD2011 per gallon	WTP	Spain	48,2%
			Russia	11,41%
			Belgium	11,26%
			Netherlands	9,04%
			China	3,97%
			Saudi Arabia	3,64%
			France	2,24%
			Italy	1,74%
			Egypt	1,49%
			Brazil	1,34%

Pellets:

Table 88 - LCI of the pellet packaging stage in Portugal, for Omnipellets (S-LCA)

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
LDPE bags	7,109336 USD2011 per kg	CRP	Portugal	12,92%
			Spain	49,02%
			Germany	8,62%
			Netherlands	7,05%
			Italy	5,51%
			Belgium	4,35%
			Vietnam	3,45%
			China	2,43%
			France	2,29%
			UK	2,13%
			India	1,18%
			Malaysia	0,87%

Table 89 - LCI of the pellet's distribution stage in Portugal, for Omnipellets (S-LCA)

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
Road transport (diesel)	1,257963 USD2011 per L	OTP	Spain	48,2%
			Russia	11,41%
			Belgium	11,26%
			Netherlands	9,04%
			China	3,97%
			Saudi Arabia	3,64%
			France	2,24%
			Italy	1,74%
			Egypt	1,49%
			Brazil	1,34%

Table 90 - LCI of the pellet's usage stage in Portugal, for Omnipellets (S-LCA)

Material	Price (USD 2011)	GTAP Sector Code	Country of origin	Country percentage
Electricity	0,156241 USD2011 per kWh	ELY	Portugal	83%
			Spain	17%