# Assessing the Social Sustainability of the three major Portuguese forest-based industries

Pulp and paper, cork and wood industries

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# Abstract

Forestry is particularly interesting from a sustainable development perspective since the first sustainability definition referred to forestry in the beginning of the 18th century, when wood was a scarce resource (von Carlowitz, 1713). Today, this sector can play an important role to achieve global sustainability at all levels, providing a range of goods and services that benefit livelihoods of people and playing an important role in local and national economies around the world. Due to its global importance, it is necessary to adopt sustainable practices along the entire forest supply chain. In addition, there is a need to study, evaluate and monitor the environmental, economic and social impacts of this sector.

Although some research exists regarding the assessment of both the environmental and economic impacts of the forest sector, there is still lack of studies analysing the social sustainability dimension of this sector. Furthermore, there was no literature found with the application of the Social Life Cycle Assessment (SLCA) to the forest-based industries. In this sense, this work aims to close this gap, applying the SLCA methodology through the Social Hotspot Database (SHDB) to quantify the social impacts of the forest sector. For the purpose of this work, the forest sector will be represented by the three most manufactured products from each major Portuguese forest-based industry, which are: uncoated woodfree paper from the pulp and paper industry, natural cork stoppers from the cork industry and particle boards from the wood industry.

According to the results obtained, the three most critical social issues for the forest sector are: Injuries & Fatalities, Occupational Toxic & Hazards and Corruption. Furthermore, most social impacts identified in the life cycle of the three products under study are related to both the Health & Safety and Labour Rights & Decent Work categories. Based on these results, recommendations for improving the social sustainability of the forest sector will be provided. In addition, a social comparison between the three forest-based industries under study was performed, concluding that the production of natural cork stoppers has the better social performance, considering the functional unit selected for this work. Nevertheless, when considering the three sustainability pillars (economic, social and environmental), it is possible to conclude that the production of uncoated woodfree paper has the best sustainability performance.

**Keywords**: Social Sustainability; Social Life Cycle Assessment; Social Hotspot Database; Social Hotspots; Forest sector; Uncoated woodfree paper; Natural cork stoppers; Particle boards.

# Resumo

A Floresta e a silvicultura são particularmente interessantes do ponto de vista do desenvolvimento sustentável, uma vez que a primeira definição de sustentabilidade se referia à floresta no início do século XVIII, quando a madeira era um recurso escasso (von Carlowitz, 1713). Nos dias de hoje, o sector florestal tem um papel importante para alcançar a sustentabilidade global, fornecendo uma variedade de bens e serviços benéficos para a sociedade, como também desempenhando um papel importante nas economias locais e nacionais em todo o mundo. Devido à sua elevada importância a nível global, é necessário adotar práticas sustentáveis transversais a toda a cadeia de abastecimento florestal. Para além disso, é fundamental estudar, avaliar e monitorizar os impactos ambientais, económicos e sociais deste setor.

Embora existam alguns estudos que avaliem os impactos ambientais e económicos do setor florestal, ainda faltam estudos que analisem o pilar social da sustentabilidade aplicada a este mesmo setor. Além disso, não foi encontrado na literatura nenhum estudo com a aplicação da Análise de Ciclo de Vida Social (SACV) às indústrias de base florestal. Nesse sentido, este trabalho visa fechar esta lacuna, aplicando a metodologia SACV por meio da Social Hotspot Database para quantificar os impactos sociais do setor florestal. Para efeitos deste estudo, o sector florestal será representado pelos três produtos mais manufaturados de cada uma das principais indústrias florestais portuguesas, sendo: papel de impressão da indústria da pasta e papel, rolhas de cortiça naturais da indústria da cortiça e painéis de partículas de madeira da indústria da madeira.

De acordo com os resultados obtidos, as três questões sociais mais críticas para o setor florestal são: Acidentes e Fatalidades, Riscos Ocupacionais Tóxicos, e Corrupção. A maioria dos impactos sociais identificados no ciclo de vida dos três produtos está relacionada com a Saúde & Segurança ocupacional como também com os Direitos do Trabalho & Trabalho Decente. Com base nestes resultados, serão fornecidas recomendações de forma a melhorar a sustentabilidade social do setor florestal. Adicionalmente, foi realizada uma comparação entre as três indústrias analisadas, concluindo que a produção de rolhas de cortiça tem o menor impacto social considerando a unidade funcional definida no estudo. No entanto, quando considerando os três pilares da sustentabilidade (económico, social e ambiental), conclui-se que a produção de papel impressão tem a melhor performance.

**Palavras-chave:** Sustentabilidade Social; Análise de ciclo de vida social; Setor florestal; Papel de impressão; Rolhas de cortiça naturais; Painéis de partículas de madeira.

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# List of Abbreviations

3BL – Triple Bottom Line

AHB – Assess to Hospital Beds

ADW – Assess to Drinking Water

AIFF – Associação para a Competitividade da Indústria da Fileira Florestal (Forestry Industry Competitiveness Association)

AS – Assess to Sanitation

BAuA – The Federal Institute for Occupational Safety and Health

C – Corruption

C&I – Criteria and indicators

CAE – Classificação das Atividades Económicas (Portuguese Classification of Economic Activities)

CD – Communicable Diseases

CELPA – Associação da Indústria Papeleira (Paper Industry Association)

CL – Child Labor

CoS – Children out of School

CPI – Corruption Perception Index

CSR – Corporate Social Responsibility

D – Discrimination

DGAE – Direção Geral das Atividades Económicas (General Direction of Economic Activities)

EHS – Environmental, Health, and Safety

ELCA – Environmental Life Cycle Assessment

EWT – Excessive Working Time

FAO – Food and Agriculture Organization

FL – Forced Labor

FoA – Freedom of Association

FSC – Forest Stewardship Council

FU – Functional Unit

GE – Gender Equity

GEE – Gabinete de Estratégia e Estudos (Strategy and Studies Office)

GRI – Global Reporting Initiative

GSCP – Global Social Compliance Programme

GTAP – Global Trade Analysis Project

HCZ – High Conflict Zones

HDV – Heavy duty vehicles

ICNF – Instituto da Conservação da Natureza e das Florestas (Institute for Nature Conservation and Forests)

IEA – International Energy Agency

IF – Injuries and Fatalities

ILO – International Labour Organization

INE – Instituto Nacional de Estatística (Portuguese National Statistical Institute)

IR – Indigenous rights

ISO – International Organization for Standardization

LCA – Life Cycle Assessment

LCC – Life Cycle Costing

LCI – Life Cycle Inventory Analysis

LCIA – Life Cycle Impact Assessment

LCSA – Life Cycle Sustainability Assessment

LLC – Labour Laws Conventions

LS – Legal System

MCPFE – Ministerial Conference on the Protection of Forests in Europe

ML – Migrant Labour

NCD – Non-communicable Diseases

NGO – Non-governmental Organization

NPV – Net Present Value

OECD – Organisation for Economic Co-Operation and Development

OSHA – Occupational Safety and Health Administration

OTH – Occupational Toxic and Hazards

P – Poverty

PCF – Processed Chlorine Free

PEFC – Programme for the Endorsement of Forest Certification

PELs – Permissible Exposure Limits

PRPs – Performance Reference Points

PSILCA – Product Social Impact Life Cycle Assessment

SA – Social Accountability

SAI – Social Accountability International

SB – Social Benefits

SCF – Smallholder vs. Commercial Farms

SDs – Sustainable Development Goals

SETAC – Society of Environmental Toxicology and Chemistry

SFM – Sustainable Forest Management

SHDB – Social Hotspots Database

SIF – Serious Injuries and Fatalities

SLCA – Social Life Cycle Assessment

SS – Single Score

TI – Transparency International

U – Unemployment

UN – United Nations

UNCED – United Nations Conference on Environment and Development

UNEP – United Nations Environment Programme

UNECE – United Nations Economic Commission for Europe

UNGC – United Nations Global Compact

UK – United Kingdom

USA – United States of America

UWF – Uncoated Woodfree paper

W – Wage Assessment

WBSCD – World Business Council for Sustainable Development

WWF – World Wide Fund for Nature

WCED – World Commission on Environment and Development

# 1. Introduction

## 1.1. Problem contextualization

Forests are among the world's most productive land-based ecosystems and are essential to life on Earth (UN, 2019). They provide solutions for addressing many development challenges including poverty eradication, agriculture, energy, biodiversity conservation, among others. Furthermore, the forest sector is of crucial importance for the European continent, being a fundamental source of economic, environmental, and social value. Forests are directly related to sustainability, contributing and promoting sustainable development at different levels. Due to their crucial importance, the United Nations (UN) Forum on Forest adopted, in 2017, the UN Strategic Plan for Forests 2017-2030, a global framework for actions to sustainably manage all types of forests and trees, as well as to halt deforestation and forest degradation (UN, 2019).

At the heart of the Strategic Plan are 6 Global Forest Goals and 26 associated targets to be achieved by 2030. They support the objectives of the international arrangement on forests and are aimed at contributing to progress on the sustainable development goals (SDGs) adopted by all UN Member States in 2015 (UN, 2019):

- **Global Forest Goal 1:** Reverse the loss of forest cover worldwide through sustainable forest management (SFM), including protection, restoration and reforestation, and increase efforts to prevent forest degradation and contribute to the global effort of climate change. SDGs: 13 – Climate Action (forests act as carbon sinks, absorbing a huge quantity of dioxide carbon each year) and 15 – Life on Land (forests cover 31% of the Earth's land area);
- **Global Forest Goal 2:** Enhance forest-based economic, social and environmental benefits, improving the livelihoods of forest-dependent people. SDGs: 2 – Zero Hunger (around 50% of the fruit consumed by humans comes from trees) and 6 – Clean Water and Sanitation (75% of freshwater comes from forest watersheds);
- **Global Forest Goal 3:** Increase significantly the area of protected forests worldwide and other areas of sustainably managed forests, as well as the proportion of forest products from these forests. SDGs: 7 – Affordable and Clean Energy (2.4 billion people use wood fuel for cooking, boiling water and heating) and 15 – Life on Land (80% of all terrestrial species live in forests);
- **Global Forest Goal 4:** Mobilize significantly increased, new and additional financial resources from all sources for the implementation of SFM and strengthen scientific and technical cooperation and partnerships. SDGs: 1 – No Poverty (40% of extreme poor in rural areas live in forests and savannas), 3 – Good Health and Well-being (2/3 of all cancer-fighting medicines come from rainforest plants), 8 – Decent Work and Economic Growth (nature-based tourism accounts for nearly 20% of the global tourism market) and 17 – Partnerships for the Goals (Official Development Assistance to forestry is around 8.6 billion dollars over the past 15 years);

- **Global Forest Goal 5:** Promote governance frameworks to implement SFM, including through UN Forest Instrument, and enhance the contribution of forests to the 2030 Agenda for Sustainable Development. SDGs: 2 – Zero Hunger (76 million tonnes of food comes from forests, 95% of which is plant-based), 7 – Affordable and Clean Energy (40% of our renewable energy is forest-based), 11 – Sustainable cities and communities (1/3 of the world's largest cities drink water from forest watersheds) and 16 – Peace, Justice and Strong Institutions (1.5 billion of indigenous people have community-based tenure over forest resources);
- **Global Forest Goal 6:** Enhance cooperation, coordination, coherence and synergies on forest-related issues at all levels, including within the UN System and other relevant stakeholders. SDGs: 5 – Gender Equity (83% of the people collecting fuelwood or producing charcoal are women), 11 – Sustainable cities and communities (trees and parks clean the air, reduce stress and improve health), 12 – Responsible consumption and production (by 2050, the world's population could reach 10 billion, requiring more forest services and products) and 15 – Life on Land (76% of the world's forests are publicly owned).

Forests and the forestry sector have always played a major role to the development of societies and to achieve global sustainability. Affecting about 20% of the world's population, forests enable the employment of millions of people around the world, maintaining biodiversity and life on Earth, and largely contributing for national economies. In Portugal, the forest sector has an important contribution on the economy of the country. The Portuguese forest-based industries (such as the pulp and paper, cork and wood industries) represented a business volume of, approximately, 10 billion euros, which corresponds to 4.93% of the National Domestic Product. Furthermore, the exports of goods from these industries reached 5 974 million euros, representing about 10% of the total Portuguese exports in 2019. In terms of social benefits, 75 324 people are employed by the companies that make up the Portuguese forest-based industries, which corresponds to 1.86% of the total personnel employed in this country (DGAE, 2020).

Due to the pressures imposed by different stakeholders, many companies start to report their efforts and improvements on sustainable practices, as well as acquire a forest certification. Forest certification is a tool of SFM with the aim of improving the quality of forest management, which has been highly adopted by companies in this sector. Sustainability reporting is another method to internalize and improve an organization's commitment to sustainable development, comprising the three dimensions of sustainability: environmental, economic and social. However, contrary to what has been observed in both the economic and environmental pillars, where the impacts of these two dimensions are well defined and measured, the social dimension of sustainability is still not yet properly assessed. The social impacts of the forest products are not quantified and the efforts on improving the social performance of the forest companies are mostly related with the safety and health of workers and the creation of jobs. Therefore, the social pillar remains poorly explored and less integrated when compared with the other two dimensions (economic and environmental). Nevertheless, it is relevant to quantify these social impacts throughout the entire value chain since the forest sector is of crucial importance for the society.

Accordingly, the aim of this research is to study, quantify and evaluate the social and socioeconomic impacts of the Portuguese forest sector, which will be represented by the three most manufactured products from each major forest-based industry: uncoated woodfree paper from the pulp and paper industry, natural cork stoppers from the cork industry, and particle boards from the wood industry. The Social Life Cycle Assessment (SLCA) will be the methodology applied in this research, enabling the quantification of the social impacts throughout all stages of the life cycle of the products under study. For a proper understanding of the matters involved, a thorough literature review on the social sustainability concept and its different methods and tools to assess this pillar has been conducted.

## 1.2. Dissertation's objective

The main objective for conducting this dissertation is to study and quantify the social impacts of the forest sector, which will be represented by the three major Portuguese forest-based industries (pulp and paper, cork and wood industries). In addition, this work aims to conduct an extensive review on the social sustainability concept as well as its methods and tools, in order to select the most appropriate methodology for the research. This dissertation will be structured to reach the following intermediate objectives. (1) Problem Identification: analysis of the forest sector as well as its importance, and a description of the concept of sustainable forest management. (2) Literature Review on the social tools and methodologies to assess social sustainability. (3) Definition of the research methodology: characterize each step of the methodology and the data collection methods. (4) Results analysis and discussion: interpretation of the results obtained, identification of social hotspots in the supply chain and propose recommendations on each industry to improve their social performance. (5) Comparison of systems: select the forest-based industry with the best social performance and formulate conclusions about the social sustainability of the forest sector in general. (6) Sustainability Assessment: formulate conclusions about the overall sustainability of each industry, considering the three pillars of sustainability.

## 1.3. Dissertation's structure

The present dissertation is constituted of six chapters:

- **Chapter 1 – Introduction:** The first chapter consists of a brief introduction to the present work, which includes a contextualization of the problem analysed and sets the main objectives of the research.
- **Chapter 2 – Problem characterization:** The second chapter provides a complete problem contextualization. The forest sector and the concept of sustainable forest management is presented and characterised. Additionally, the Portuguese forest sector is described, focusing on the three major forest-based industries (pulp and paper, cork and wood) and its link with the concept of sustainability.
- **Chapter 3 – State of Art:** Since the problem has been identified, a theoretical analysis is required and is presented in this chapter, providing a state of the art on the sustainability and the triple bottom line concepts, as well as on the different methods and tools available to monitor and evaluate the social sustainability of different organisations. Furthermore, the link between

the social sustainability and the forest-based industries will also be studied, discussing what has been researched in this field, and identifying the main gap that exists in the literature, which will be the main motivation for conducting this work.

- **Chapter 4 – Research Methodology:** This chapter illustrates the three main steps that compose the research methodology, which are: Step 1 – SLCA application for each forest-based industry, considering the four sub-steps of the LCA methodology (1.1. Goal and scope definition; 1.2. Life cycle inventory; 1.3. Life cycle impact assessment; and 1.4. Interpretation); Step 2 – Comparison of Systems; Step 3 – Sustainability Assessment.
- **Chapter 5 – Results Analysis and Discussion:** This step comprises three main sections, corresponding to the three steps of the research methodology identified in the previously chapter. In the fifth chapter, the results obtained through the SLCA methodology combined with the Social Hotspot Database (SHDB) will be interpreted, including recommendations for all the stakeholders involved in the forest sector. Furthermore, a comparison between the three forest-based industries will be conducted, and the most sustainable product will be selected in the last section of this chapter.
- **Chapter 6 – Conclusions and Future Work:** This last chapter presents an overview to the dissertation, identifying the main conclusions and limitations that were obtained through the development of this study. In addition, this section aims to reflect about the future work that needs be done regarding the assessment of the social sustainability of the forest sector by applying the SLCA methodology combined with the SHDB.

# 2. Problem characterization

This chapter is divided into five sections. Section 2.1 provides an overview of the forest sector and its importance to achieve global sustainability, as well as an introduction to the concept of sustainable forest management. Section 2.2 describes the Portuguese forest sector and its major forest-based industries: pulp and paper, cork and wood industries. Section 2.3 establishes the link between the Portuguese forest-based industry and the concept of sustainability. Finally, section 2.4 characterizes the problem identified, which will be the focus of this work.

## 2.1. Forest sector

A sector is "*a part of the economy that has certain common characteristics which enable it to be separated from other parts of the economy for analytical or policy purposes.*" (Pass et al., 1993). The forest sector is the part of the national economy concerned with forests and the goods and services that forests supply (Gane, 2007). Hence, all the economic activities based on the exploitation of forest resources should be included in the sector. However, it is difficult and complex to know which activities are really dependent on forest and, for this reason, there is still not a commonly agreed definition for this sector (FAO, 2014; Baumgartner, 2019).

The definition of the forest sector has a significant impact on the final results of a study, as it determines which forest industries and activities are included. Furthermore, how forest industries are grouped and divided into different subsectors may affect the estimates of economic and social contributions of each subsector (Li et al., 2019). According to the Food and Agriculture Organization of the United Nations (2014), the forest sector should include all the commercial activities related to the production and processing of wood fibre (e.g., wood fuel and charcoal, pulp and paper, roundwood, wooden furniture), non-wood forest products (e.g., honey, mushrooms) and all the economic activities concerning the production of forest services (waste treatment, water supply) (FAO, 2014).

The forest sector is composed by resources, activities and outputs and the interactions between these three components create value by converting resources into activities and activities into outputs, see Figure 1. Forest resources could be natural (e.g., land, water, soil and the most important one, forest), human (that includes people dependent on the forest for their livelihoods, such as cultivators, and people employed in forestry or forest industries) and capital (made up of the physical assets obtained by investments (for instance buildings, factories, machinery). Regarding the activities of the forest sector, its principal objective is to provide different kinds of outputs in response to the needs of consumers. The sector, that should be treated holistically, could be subject to external influences at three different levels: activities in other sectors, the behaviour of the national economy and international actions (Gane, 2007).

Figure 1: The three components of the forest sector (Adapted from Gane, 2007)

The forest sector provides several benefits for the society and plays an important role in local and national economies around the world, contributing to a country's progress towards economic growth, social well-being and environmental sustainability (Li et al., 2019). In order to better understand the overall importance of forests, the next topic will address its contribution to achieve global sustainability at different levels.

### 2.1.1. The importance of forests

Forests are among the world's most productive land-based ecosystems and are essential to life on Earth (UN, 2019). They provide solutions for addressing many development challenges including poverty eradication, food security and agriculture, energy, biodiversity conservation, and many others. Additionally, the forest sector can make a significant contribution towards meeting green economy objectives linked to climate change policies. The sector plays a crucial role to accomplish global sustainability, and for this reason, forest resources must be preserved and protected against excessive exploitation or other disturbances (UNECE & FAO, 2009). According to the World Business Council for Sustainable Development (2015), the main reasons why forests play a key role in achieving global sustainability are the following (WBCSD, 2015):

- The forest products industry employs 14 million people globally and forests directly affect the livelihoods of 20% of the world's population;
- Energy from wood is the most important source of renewable energy, representing 9% of the total primary energy supply worldwide;
- Forests are the habitat for more than 80% of the existing terrestrial biodiversity. Managed forests play a key role in reducing pressures on natural forests, connect fragmented ecosystems and make an important contribution to conserving biodiversity and human well-being;
- Forests provide a natural water treatment that significantly reduces the cost and provides multiple water ecosystem services by controlling floods and droughts, reducing erosion risks and protecting watersheds;
- Forests are responsible for the most effective and cost-competitive natural carbon capture and storage system, removing an equivalent of 693 million tonnes of carbon dioxide from the atmosphere annually. The global forest carbon stocks are estimated to be 27 times the world's annual carbon emissions from fossil fuels.

Despite the crucial contribution of forests to life on earth and human well-being, deforestation and forest degradation continue in many regions, driven by different factors (UN, 2017). The forest area, as proportion of total land area, decreased from 32.5% to 30.8% between 1990 and 2020, primarily caused by agricultural expansion to meet the rising demand (FAO & UNEP, 2020). Approximately 80% of global deforestation is caused by expansion of land used for agriculture (European Commission, 2019). The combination of the increasing demands from a growing global population (for food, bioenergy, timber) with low productivity and low resource efficiency, put more pressure on land use. Consequently, it is required action from political and private actors on all levels (Baumgartner, 2019). In this sense, the concept of sustainable forest management has emerged and became even more critical and, at the same time, an important tool for the forest sector to adapt to climate change (FAO, 2009).

### 2.1.2. Sustainable Forest Management

Forestry is particularly interesting from a sustainable development perspective since the first sustainability definition referred to forestry in the beginning of the 18th century, when wood was a scarce resource (von Carlowitz, 1713). Initially, the concept of forest sustainability was developed mainly in the context of ensuring sustainable timber production and meeting economic objectives. However, in recent years, the scope of sustainable forest management has broadened to cover social, cultural and environmental forest values equally (FAO, 2020). Due to several ecosystem services provided by forests to the community, the multifunctional management of forests has acquired an important role in recent years (Riccioli et al., 2020).

In the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro (1992), where international forest principles and sustainable development goals (SDs) were formulated for the first time, the notion of Sustainable Forest Management (SFM) was born and rapidly gained interest (Holvoet & Muys, 2004). Sustainable forest management is defined as "*a dynamic and evolving concept, which aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations."* (FAO, 2020). Since then, several countries throughout the world have developed regional and international initiatives and tools that can measure and monitor success in achieving forest sustainability (Siry et al., 2005). Criteria and indicators (C&I) and forest certification are two voluntary instruments to promote sustainable forest management (Rametsteiner & Simula, 2003).

In Europe, this trend was taken into account at the Ministerial Conference on the Protection of Forests in Europe (MCPFE) held in Helsinki, in 1993 (Wolfslehner et al., 2005). The concept of SFM was adopted and defined as "*the stewardship and use of forest lands in a way and at a rate that maintains their productivity, biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil now and in the future relevant ecological, economic and social functions at local, national and global levels and that does not cause damage to other ecosystems."* (MCPFE, 1993).

In the follow-up process of the MCPFE Helsinki Conference, six criteria in Europe were defined, aiming at the maintenance, conservation and adequate improvement of:

1. Forest resources and their contribution to global carbon cycles;
2. The health and vitality of the forest ecosystem;
3. Forest production functions (wood and non-wood forest products);
4. Biological diversity in forest ecosystems;
5. Protective functions in forest management (in particular, soil and water);
6. Other socio-economic functions and conditions.

Sustainable forest management is a concept specifically designed to embrace and reconcile the different stakeholder's interests on forests. They range from public or private forest owners to local communities or indigenous peoples, forest industry and environmental non-governmental organisations (NGOs). This interests normally require trade-offs and some are simply mutually exclusive (Rametsteiner & Simula, 2003). Such trade-offs are likely, especially between economic goals on the one hand and environmental or social goals on the other hand. An example is an intensively managed forest that maximizes the output of wood with a minimum of emissions due to the efficient use of machinery, but this is usually on the cost of biodiversity and ecosystem quality (Baumgartner, 2019).

Global forests resources are essential for the conservation of biological diversity as well as for meeting the need for wood and non-wood forest products. The forest sector plays an important role in the transition to a sustainable society (Baumgartner, 2019). In order to help country stakeholders unlock the forest sector's full potential and achieve the goal of sustainable development, it is important to understand the sector's contribution to national economies (Li et al., 2019). Therefore, the next topic will address the contribution of the forest sector to the Portuguese economy, focusing on the three major forest-based industries in this sector, which are the pulp and paper, cork and wood industries.

## 2.2. The Portuguese forest sector

The forest sector is of crucial importance for the European continent, being a fundamental source of economic, environmental and social value. As in Europe, forests represent the dominant land use, occupying 36.3% of mainland Portugal (over an extension of more than 3 million hectares) (ICNF, 2015). However, the national forest is distinguished of most European countries since it is mostly (97%) private property (the European average is 60.2% with Portugal leading the ranking) (Eurostat, 2017).

Due to the large dimension of the forest sector, a division into groups must be made, in order to better understand the economic and social contributions of each identified group. Thus, for further analysis, the forest sector will be divided into three main groups, which are:

- Forestry and logging – corresponding to the division 02 of CAE (Portuguese Classification of Economic Activities) rev. 3.
- Forest-based industry – composed by the division 16, 17 and 31 of CAE rev. 3, which are, respectively, wood and cork, pulp and paper and wooden furniture industries.
- Forest-based trade – composed by all the commercial activities (i.e. wholesale and retail trade) related to paper, cardboard, cork, wood and wooden furniture.

The three mentioned groups - forestry and logging, industry and forest-based trade - represent an important value chain for Portugal, contributing for the creation of wealth in economic and social terms. This impact is reflected in the dimension of jobs and companies operating in the sector, see the chart in Figure 2. In 2016, the sector employed a total of 112 974 people (2.5% of the personnel employed in Portugal) distributed in 24 141 companies (ICNF, 2018; GEE, 2020a; DGAE, 2020).

Figure 2: Number of jobs and companies in the Portuguese forest sector (ICNF, 2018; GEE, 2020a; DGAE, 2020)

All the three groups mentioned previously have an important impact on the national economy. However, it is the forest-based industry (cork and wood, pulp and paper and wooden furniture) that represents the most weight. In 2018, this industry accounts for 75 324 jobs that produced a business volume of, approximately 10 billion euros, which corresponds to 4.93% of the National Domestic Product. Additionally, the exports of goods from the industry reached 5 974 million euros, representing about 10% of the total Portuguese exports in 2019 (DGAE, 2020). Furthermore, it is important to refer that forestry and logging and the forest-based industry represented both, in 2018, a Gross Value Added of 2 810 million euros, which corresponds to approximately 1.6% of the total Gross Value Added of the country (DGAE, 2020; GEE, 2020a).

The most common species in the Portuguese forest are *Eucalyptus* (26.2%), followed by *Quercus suber* (22.3%) and *Pinus pinaster* (22.1%) (ICNF, 2015). These tree species are responsible for providing the raw material for the three major forest-based industries in the country, which are the pulp and paper industry (mainly from *Eucalyptus),* the cork industry (from *Quercus suber)* and the wood industry (mostly from *Pinus pinaster).* Due to its importance to the Portuguese forest sector, each industry will be described further in the next sections.

### 2.2.1. The pulp and paper industry

*Eucalyptus* (specifically *Eucalyptus globulus*) is a tree species native to south-eastern Australia, mainly cultivated in the Iberian Peninsula to be used in the pulp, paper and cardboard industry (Cerasoli et al., 2016). *Eucalyptus* is the most common specie in Portugal, with a total area of 845.01 thousand hectares in the country (ICNF, 2015).

Regarding the forest-based industries, the pulp and paper sector is the one that represents the greatest turnover, counting with a business volume of 4 658.05 million euros in 2018, which corresponds to 4.89% of the manufacturing industry and 2.28% of the Gross Domestic Product of Portugal. In the same year, the sector accounts for 11 806 jobs and 580 companies, mostly (54.83%) located in the north of the country (DGAE, 2020). The exports of goods from the pulp and paper industry, approximately 2 595.14 million euros in 2019, represent 4.33% of the total exports of Portugal and 43.4% of the total exports from the forest-based industries (DGAE, 2020). The main destinations are Spain, counting with a value of 602.06 million euros followed by France and Germany. Regarding the imports, Spain is the main supplier with an equivalent value of 764.59 million euros (DGAE, 2020).

Portugal is the third largest European pulp producer, with a market share of 7.2%, just behind Sweden and Finland. At the same time, the country is also the second largest producer of uncoated woodfree (UWF) paper and cardboard, representing 17.9% of the total production of this type of paper and cardboards (CELPA, 2019).

The three most manufactured products in the industry are uncoated woodfree (UWF) paper, cartonboard and papers for packaging, and household and sanitary papers (ICNF, 2018). Since the uncoated woodfree (UWF) paper is the most manufactured, this product will be the selected one for further analysis.

### 2.2.2. The cork industry

*Quercus suber*, commonly known as cork oak, is a tree species native to the Mediterranean region and most noted for its thick bark (cork) used in the cork industry (Houston Durrant et al., 2016). With a lifespan of over 200 years, the cork oak tree is a paradigm of sustainability, being the only oak species whose bark regenerates, acquiring a smoother texture following each harvest (Corticeira Amorim, 2020). Cork oak forests cover an area of 2 123 thousand hectares worldwide, with Portugal counting for 34% of this area, which corresponds to 719.94 thousand hectares (ICNF, 2015; APCOR, 2019). *Quercus suber*, the second most dominant forest specie in Portugal, is mostly located in the south of the country, with Alentejo occupying 85% of the total area (ICNF, 2015).

The world cork production rose to 201 thousand tonnes, with Portugal being the leader in the production, followed by Spain and Morocco. The annual average production of cork in the country is 100 thousand tonnes, which corresponds to almost half (49.6%) of the world's total production of cork (APCOR, 2019). In 2018, the sector employed 8 627 workers operating in 841 companies, producing roughly 40 million cork stoppers per day (APCOR, 2019; DGAE, 2020). Furthermore, the cork industry's business volume was approximately 1 761.21 million euros in the same year, which corresponds to 0.86% of the National Gross Domestic Product (DGAE, 2020). Regarding the exports of goods from the cork industry, Portugal is once again the world's leader, exporting a value of, approximately, 987.16 million euros, which represents 1.65% of the total Portuguese exports of goods, being France the main destination (DGAE, 2020). Despite being a leader in the sector, Portugal is still the third highest importer of cork in the world, using it for processing and then export in the form of consumer end products (APCOR, 2019). Cork imports are mainly from Spain, followed by Morocco and Germany (DGAE, 2020).

The three most manufactured products in the industry are natural cork stoppers, followed by building materials and other types of cork stoppers (e.g., champagne stoppers). The chosen product for further analysis in this project is the natural cork stoppers since it is the most manufactured product and, at the same time, the one that is more exported by the country, representing 43% of the total exports from cork, in units of value (ICNF, 2018).

### 2.2.3. The wood industry

*Pinus pinaster*, commonly known as maritime pine, is a tree species native to the western Mediterranean basin (Abad Viñas et al., 2016). With a total area of 713.25 thousand hectares in Portugal, *Pinus pinaster* is the third most common in the country (ICNF, 2015). The wood is the major product that is obtained from maritime pine, which has a broad range of final products (Abad Viñas et al., 2016).

In 2018, the wood industry (excluding wooden furniture) employed 21 121 people which represents 0.52% of the total personnel employed in Portugal. Additionally, the sector accounts for 4 190 companies, mostly (45%) located in the north of the country. The business volume of the wood industry was 1 729.86 million euros, 1.82% of the manufacturing industry and 0.85% of the Gross Domestic Product of Portugal (DGAE, 2020). The exports of goods from the wood industry, approximately 585.47 million euros, corresponds to 0,98% of the total exports in the country. The main destinations are Spain, United Kingdom, France, Denmark and The Netherlands. Together, these five countries represent 71.5% of the total exports in this industry. Once again, wood imports are mainly from Spain, with a value of 142.49 million euros, followed by Germany and the United States of America (DGAE, 2020).

The most manufactured products in the wood industry are particle boards, followed by fibreboards (e.g., medium-density fibreboards) and plywood and veneer sheets (ICNF, 2018). Since particle boards are the most manufactured, this product will be the selected one for further analysis.

To conclude, these three forest-based industries are an important source of value to the Portuguese economy and people, having a significant contribution to the National Gross Domestic Product, as well as providing several jobs for the society. Due to its relevance in economic and social terms, it is necessary and crucial to adopt sustainable practices along their activities, in order to preserve resources and contribute to a sustainable development. Therefore, the next section will establish the link between the Portuguese forest-based industry and the concept of sustainability.

## 2.3. Forest-based industry and sustainability

In the current economic context, the long-term success of any organisation or industry should be built not only on profitability but also on its contribution to the future of people and planet (Bubicz et al., 2019). Organisations need to adopt sustainable practices along their supply chains, as a part of long-term strategy that seeks competitive advantage (Levesque, 2012). An instrument to improve sustainability practices in the forest sector is forest certification schemes, a marked-based initiative aimed at improving the quality of forest management (Siry et al., 2005; Baumgartner, 2019). Forest certification deals with different stakeholders and their respective interests. For industry and trade, it is an instrument for environmental marketing and market access. For buyers and consumers, it provides information on the impacts of products they purchase. For forest owners and managers, it is a tool for market access or gaining market advantage. For governments, it is as soft policy instrument to promote SFM and sustainable consumption patterns. For environmental movement, it is a means to influence how forests are managed to promote biodiversity maintenance (Rametsteiner & Simula, 2003).

In this sense, the “Associação para a Competitividade da Indústria da Fileira Florestal” (AIFF) launched one of their major challenges: a forest certification project named “Certifica +” (AIFF, 2020). The certification project was developed for the three main forest-based industries (pulp and paper, cork and wood) with the aim to provide all the necessary information required to obtain a forest certification, according to the FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification), the two main international certification systems (Baumgartner, 2019; AIFF, 2020).

Regarding the results of the certification project “Certifica +”, it reached all the success indicators to which the association (AIFF) had proposed, namely the increasing of:

- The certified forest area by 5%;
- The number of companies with a certified responsible supply chain by 7%;
- 5% in the sales of cork stoppers, pulp, paper and cardboards;
- The volume of exports in the wood industry up to 2.5%.

In order to better understand how companies of each forest-based industry implement sustainable practices along their supply chains, Table 1 summarizes the types of sustainability assessment, as well as forest certifications of six major Portuguese companies (two companies for each forest-based industry). As it can be observed in Table 1, all the selected companies, excepting the company “Interpall” from the wood industry, have already a forest certification according to FSC and/or PEFC. Furthermore, “Corticeira Amorim” was the first packaging company in the world to achieve, in 2004, the FSC certificate in the cork industry (Corticeira Amorim, 2019). However, only three of the companies selected report their sustainable practices to their stakeholders through a sustainability report, according to the Global Reporting Initiative (GRI) guidelines (this theme will be later discussed in the section 3.2.3), as well as mention the sustainable development goals (SDs) formulated by the UNCED. Especially in the wood industry, there is still a lack of reporting sustainable practices, since none of the companies operating in this industry has a sustainability report. In this sense, it is necessary more effort in reporting, addressing and incorporating the concept of sustainability in the entire supply chain of many companies in the forest sector.

Table 1: Type of sustainability assessment and forest certification of six major companies operating in the Portuguese forest-based industry

| Company | Industry | Forest Certification | Type of Sustainability Assessment |
|---|---|---|---|
| The Navigator Company | Pulp and paper | FSC and PEFC | Sustainability report (GRI and SDs) |
| Altri Group (Celbi, Celtejo and Caima) | Pulp and paper | FSC and PEFC | Sustainability report (GRI and SDs) |
| Corticeira Amorim | Cork | FSC | Sustainability report (GRI and SDs) |
| Granorte | Cork | FSC | Sustainability statement on website |
| Unimadeiras, S.A. | Wood | FSC and PEFC | Sustainability statement on website |
| Interpall | Wood | - | - |

Regarding the three companies that report their sustainable practices, they address social, environmental and economic indicators in their reports, which are summarized in Table 2. As it can be observed, the sustainability reports of the selected companies are more focused on the social and environmental dimension of sustainability since the number of indicators for these two dimensions are higher than for the economic one. This can be due to the fact that, in general, companies report annually their economic performance to their stakeholders and investors through a Financial Report.

Regarding the social dimension, the most common indicators presented in the sustainability reports of the three companies are Human Capital Development, Safety and Human Health, and Community Involvement. On the other hand, regarding the environmental dimension, the most addressed indicators are related to Carbon Emissions as well as to the Responsible Consumption of Resources (such as raw material, energy, water). In general, the economic and environmental indicators can be quantified (through economic numbers, quantity used of resources or even the amount of Carbon emissions) along the entire supply chain. However, most social indicators cannot be quantified along the entire chain and thus, social impacts of the production activities related to these companies are still not yet assessed. Moreover, social indicators are mostly related to workers/employees through Job creation and Occupational safety and health, while there are missing areas to address (e.g., suppliers, government) which are also important. In this sense, social indicators are often procedural and do not measure salient outcomes (Sheppard et al., 2007). Nevertheless, it is relevant to evaluate these impacts since the forest sector is of crucial importance for the society. Therefore, the social dimension requires more research, in order to monitor and quantify the impacts, as it is done for the other two dimensions (economic and environmental).

Table 2*:* Social, Economic and Environmental indicators identified by the three companies reporting sustainable practices

| | Social Indicators | Economic Indicators | Environmental Indicators |
|---|---|---|---|
| **The Navigator Company** | Talent management & Human Capital Development; Safety & Human Health; Clients Satisfaction; Community Involvement | Innovation; Research & Development | Sustainable Forest Management; Energy & Climate; Industrial Environmental Management |
| **Altri Group (Celbi, Celtejo and Caima)** | Human Capital Development; Safety & Human Health; Talent Attraction; Community Involvement | Product Quality; Operational Ecoefficiency | Responsible Consumption of Raw Materials, Water and Energy; Carbon Emissions; Circular Economy; *Green Bonds* |
| **Corticeira Amorim** | Human Capital Development; Safety & Human Health; Community Involvement; Participation in Associations | Research, Development & Innovation; Economic Performance | Promotion of Biodiversity & Ecosystem Services; Energy Efficiency & Climate Change; Environmental Impact of the Product; Circular Economy |

## 2.4. Problem characterization

The recent economic downturn and the current changes in the production and consumption habits have been building up pressure in today’s society towards a more sustainable world. Despite the crucial contribution of forests to life on earth and human well-being, deforestation and forest degradation continue in many regions, mainly caused by expansion of land used by agriculture. The increasing demands from a growing global population for food, bioenergy, timber, combined with low efficiency and productivity, put more pressure on land use and threaten the conservation of the world’s forests (European Commission, 2019). In this sense, the concept of sustainable forest management (SFM) has emerged and became an extremely relevant topic both in forest and sustainability policies (Wolfslehner et al., 2005). Forest certification is a tool of SFM which has been highly adopted by companies in the sector. Additionally, increased interest for sustainability has been provoking companies to deepen their research in sustainability reporting. However, there is still a lack of companies in the forest sector reporting their sustainable efforts to their stakeholders through a sustainability report. Moreover, when assessing social sustainability, the quantification of social impacts is still not assessed as it is done for the economic and environmental ones. Due to the increased stakeholders’ pressures and awareness on the overall possible impacts along the entire supply chains, there is also a need of studying the social component, through the quantification of social impacts (Popovic et al., 2016).

Furthermore, the forest sector is of extremely importance for the world’s economy, and also of enormous relevance for the economic panorama in Portugal. The sector is an important source of wealth in economic terms (through the creation of value and Gross Domestic Product) and social terms (through job creation). Forest-based industries provide economic, environmental and societal impacts that need to be properly quantified using tools that can assess and compare different products from forests. Moreover, the role of people in forestry is of tremendous relevance from a social sustainability perspective (Baumgartner, 2019). In this sense, this work aims to study and quantify the social impacts of the forest sector, which will be represented by the three most manufactured products from each major Portuguese forest-based industry, which are: uncoated woodfree (UWF) paper from the pulp and paper industry, natural cork stoppers from the cork industry, and particle boards from the wood industry.

# 3. State of Art

This chapter provides the theoretical and scientific background that will be used to deal with the problem identified in the previous chapter. Accordingly, in section 3.1, the sustainability and the triple bottom line concepts are introduced. Then, section 3.2 is dedicated to the description of the different methods and tools to evaluate the social performance of organisations. The social sustainability applied to forest-based industries are studied in section 3.3. Finally, the gap that exists in the literature is presented in section 3.4.

## 3.1. Sustainability

### 3.1.1. Concept and definitions

Over the past few decades, the concepts of sustainability and sustainable development have emerged as humanity has become more cognizant of its increasing impact on the world (Hutchins & Sutherland, 2008). One of the most cited definitions of Sustainable Development (Azapagic & Perdan, 2000) was established in the Brundtland report by the World Commission on Environment and Development (WCED) which stated that sustainable development *"meets the needs of the present without compromising the ability of future generations to meet their own needs"* (WCED, 1987, p. 15). Since then, the application of the sustainability concept has become a fundamental issue for the successful management of organizations and, for this reason, it has been integrated into the mission of numerous organizations and institutions, from local to international in scale (Hutchins & Sutherland, 2008; Bubicz et al., 2019).

Companies are becoming more aware of the environmental and social impacts caused by their activity and seek to adopt sustainable practices (Bubicz et al., 2019). The main reason behind this adoption is the pressure imposed by the stakeholders, such as consumers, workers, environmental agencies, communities, NGOs and public regulation (Seuring & Müller, 2008; Vermeulen & Seuring, 2009). Furthermore, consumers are more frequently questioning where, by whom and under what conditions their products are being sourced and produced (Wolf, 2011; Benoit-Norris et al., 2012). Nevertheless, defining a sustainable strategy is not an easy task for organisations, as measurements of sustainability performance are not coherent and, currently, no models exist that fully translate all sustainability aspects (Azapagic & Perdan, 2000; Sarkis et al., 2010). Some of the main factors that reflects this complexity have been identified by the scientific community, as follows: 1) the concept of sustainability is still not clearly defined (Azapagic & Perdan, 2000); 2) sustainability is divided into economic, social and environmental dimensions, which creates complexity and raises problems (Sheppard et al., 2007); 3) several and conflicting stakeholders expectations must be taken into consideration; 4) it is necessary to exist a robust and transparent relationship between all the entities along the supply chain, both upstream and downstream (Vermeulen & Seuring, 2009; Wolf, 2011; Meckenstock et al., 2016).

Despite these complexities, many authors agree that sustainable development is about satisfying social, environmental and economic goals. These three dimensions are effectively attached and linked together to form the most generalised and central framework of sustainable development (Azapagic & Perdan, 2000; Vermeulen & Seuring, 2009): the Triple Bottom Line.

### 3.1.2. The Triple Bottom Line

The Triple Bottom Line (3BL) concept was presented for the first time in 1994 by John Elkington and thoroughly defined in a book entitled *Cannibals with Forks: the Triple Bottom Line of 21st Century Business*, as follows: "*Triple Bottom Line accounting attempts to describe the social and environmental impact of an organization's activities, in a measurable way, to its economic performance in order to show improvement or to make evaluation more in-depth"* (Elkington, 1998; Elkington, 2004). Elkington felt that the social and economic dimensions, already identified in 1987's Brundtland Report by the WCED, would have to be addressed in a more integrated way if real environmental progress was to be made (Elkington, 2004). Therefore, the model looks at sustainability as the intersection of environmental, social and economic performance, being each dimension equally important (Elkington, 1998). This intersection is represented in Figure 3. Later, he also developed the 3P formulation, that stands for "People, Planet and Profits", to clarify the meaning of the three pillars presented in the previous concept (Elkington, 2004).

The 3BL concept quickly became popular and several organisations (e.g., Royal Dutch Shell) start to adopt the model to demonstrate to their stakeholders the progresses over sustainability and efficiency in the long term (Elkington, 2004; Closs et al., 2011). The main reason why companies choose this approach is to reduce the negative environmental and social impacts of corporate activities, while improving (or at least not reducing) the economic performance of the corporation (Baumgartner & Rauter, 2017). A critical requirement for managing the triple bottom line involves properly assessing risk and making the necessary trade-off decisions to enhance long term value (Closs et al., 2011).

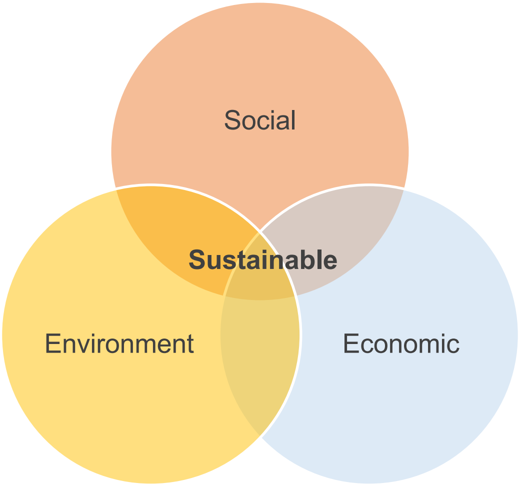


Figure 3: Representation of sustainability as three intersecting circles (Purvis et al., 2019)

**Economic Dimension**

Economic sustainability refers to the competitiveness of a company (Baumgartner & Rauter, 2017). According to the Global Reporting Initiative (2013, p. 67), the economic dimension of sustainability *"concerns the organisation's impacts on the economic conditions of its stakeholders, and on the economic systems at local, national and global levels"*. Hence, economic indicators illustrate the flow of capital among different stakeholders and the main economic impacts of the organization throughout society. The term "economic" is used in a relatively broad sense, since it encompasses topics like cost reductions, innovation and technology management, collaboration, organizational processes, knowledge management, among others (Baumgartner, 2019).

The economic dimension has always been addressed by organisations to assess sustainable practices and, traditionally, only this dimension was covered in the sustainability concept (Edum-Fotwe & Price, 2009). One reason for this can be due to the fact that the economic pillar is the most well understood and, at the same time, the one of easier measurement (Gimenez et al., 2012).

### Environmental Dimension

As stated in the Global Reporting Initiative (2013, p. 84), the environmental dimension of sustainability *“concerns an organization’s impacts on living and non-living natural systems, including land, air, water and ecosystems”.* Thus, environmental indicators cover performance related to inputs (e.g., energy, water), outputs (e.g., emissions, waste) and also related to biodiversity and other relevant environmental influences of the product over the life cycle (GRI, 2013; Baumgartner, 2019).

Due to the increasing awareness of the negative impacts of some products on the environment, companies are more frequently asked to rethink their environmental practices across their supply chains (Seuring & Müller, 2008). Hence, organisations need to implement environmentally friendly production by considering not only the activities within their own factory but also within the entire production chain (De Ron, 1998).

### Social Dimension

The social dimension, the one that has received little attention, *“concerns the impacts an organization has on the social systems within which it operates”* (Sarkis et al., 2010; GRI, 2013, p. 142). Social sustainability is *“the management of practices, capabilities, stakeholders and resources to address human potential and welfare both within and outside the communities of the supply chain”* (Chanda et al., 2017). On a corporate level, social sustainability means organizations add value to their communities by increasing the human capital of individuals and furthering the societal capital of communities (Dyllick & Hockerts, 2002). The social pillar takes into account a large range of subjects, such as education, employee relations, business practices and community involvement (Closs et al., 2011). Hence, the scope of social sustainability has the potential to be enormous, largely due to poorly defined boundaries (Sheppard et al., 2007). Moreover, the breadth of concepts allocated to this dimension creates a significant challenge when attempting to internalize and operationalize social sustainability (Sutherland et al., 2016).

In 2008, Seuring and Müller conclude that a deficit exists in terms of the social pillar of sustainability in sustainable supply chain management in general. Chazara et al. (2017) trace back the difficulties with social assessment, which are: 1) the lack of theoretical underpinning; 2) the complexity and diversity of social issues; 3) the subjective and qualitative nature of social indicators; and 4) the availability of data.

The increased awareness of the importance of environmental protection, and the possible impacts associated with products, both manufactured and consumed, has increased interest in the development of methods to better understand and address these impacts (ISO 14044, 2006). One of the techniques developed for this purpose is the Environmental Life Cycle Assessment (ELCA), normally referred to as Life Cycle Assessment (LCA) (UNEP, 2009). LCA is used to quantify the environmental impacts of a product or service over its life cycle, including raw material extraction, manufacture, distribution, use, and disposal (SHDB, 2019). The methodology, which is standardized by ISO 14040, consists on four phases: Goal and Scope, Inventory Analysis, Impact Assessment and Interpretation. The framework is represented in Figure 4.

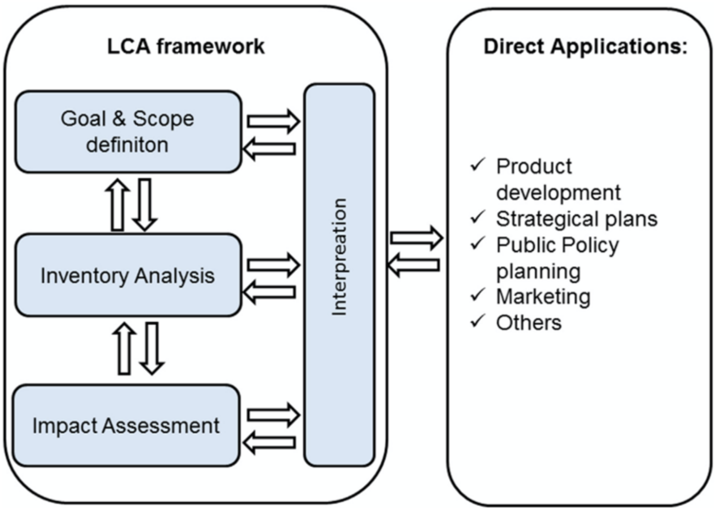


Figure 4: LCA Framework (Mehmeti et al., 2016)

Initially, only two out of the three pillars were commonly discussed and taken into account: the environmental and the economic ones (Bubicz et al., 2019). The economic pillar is assessed by the Life Cycle Costing (LCC), a method that takes into account costs incurred over the entire supply chain, use phase, and end-of-life (Benoit-Norris et al., 2012). Economic (through LCC) and environmental (through LCA) systems were frequently optimised together, leaving the third pillar in the background (Edum-Fotwe & Price, 2009). Thus, the social dimension is commonly viewed as a side aspect compared to economic and environmental ones (Messmann et al., 2020). In this sense, it was recognized a need on the integration of social criteria and the necessity to access social and socioeconomic impacts. This call for researches motivated sustainability practitioners to study and to develop techniques to assess the social dimension of sustainability (Ramos Huarachi et al., 2020). Thus, in the last decades, an increasing number of principles, tools, standards and methodologies related with the social dimension has gained prominence (Garrido, 2017). However, due to a lack of homogeneity in social assessment, comparable to the environmental one, most of the frameworks choose their set of relevant aspects and respective indicators individually (Messmann et al., 2020). Hence, the inclusion of social aspects in engineering methods always represents a challenge for sustainability practitioners (Ramos Huarachi et al., 2020).

To take socially responsible decisions, organisations have to know the different methods and tools available to achieve their sustainability goals (D'Eusanio et al., 2019). In the following section, different methodologies and social sustainability tools will be presented and discussed.

## 3.2. Social sustainability methods and tools

### 3.2.1. Corporate Social Responsibility

Corporate Social Responsibility (CSR) is closely related to social sustainability, as it comprises a set strategies, subjects and initiatives to achieve social sustainability. Hence, both terms have frequently been used interchangeably (Jenkins, 2004; Sarkis et al., 2010). CSR appears as a broader form of addressing social concerns as it incorporates both economic and environment factors, addressing the three dimensions of sustainability in an integrated way (Bubicz et al., 2019). CSR is frequently used to frame company attitudes, strategies and relationships with stakeholders, while addressing ethical values, economic well-being, and compliance with legal requirements (Sarkis et al., 2010). Although there is still no clear definition (Coelho et al., 2003), the European Commission (2011) has put forward a simpler definition of CSR as follows: *"the responsibility of enterprises for their impacts on society"* and states that in order to fully meet their social responsibility, enterprises should *"have a process in place to integrate social, environmental, ethical human rights and consumer concerns into their business operations and core strategy in close cooperation with their stakeholders"* (European Commission, 2011). In short, CSR may be succinctly stated by saying that an enterprise is responsible for the impacts created by its operations that affect stakeholders, both positively and negatively, directly and indirectly, while pursuing profitability and growth (Sutherland et al., 2016).

A strategic approach to CSR is increasingly important to the competitiveness of enterprises as it can bring benefits in terms of risk management, cost savings, access to capital, customer relationships, human resource management, and innovation capacity. Additionally, and since CSR requires engagement with internal and external stakeholders, it enables enterprises to anticipate their actions, developing new markets and creating opportunities to grow (European Commission, 2011). It must be noted that CSR is seen as a tool, commitment, process, and/or principle (Dahlsrud, 2008). Although widely used, CSR best practices remain subjective and inconsistent (Sutherland et al., 2016), since there are several indices and auditing frameworks (such as ISO 26000, SA 8000, GRI) to address this concept (D'Eusanio et al., 2019). The challenge to decision makers becomes which criteria apply, how to apply them, and if implemented, how to measure them. Further, there is no consensus on the tools and guidelines that are needed to measure and evaluate social responsibility and performance (Sutherland et al., 2016). Nevertheless, the next subtopic will describe in detail two important international standards of CSR.

### 3.2.2. ISO 26000 and SA 8000

International Organization for Standardization (ISO) is the world's largest developer of voluntary International Standards, helping to make industry more efficient and effective. Since it was founded in 1947, ISO has published more than 19 500 International Standards covering almost all aspects of technology and business (GRI & ISO, 2014). ISO 26000 (Social Responsibility) was developed through an international consensus of many stakeholders' groups and it provides guidance on how businesses and organizations can operate in a socially responsible way (e.g., transparency, respect for human rights). Hence, the emphasis is on the organization, rather than the product supply chain (Benoît-Norris et al., 2011). ISO 26000 (2010) defines social responsibility as the "*responsibility of an organization for* *the impacts of its decisions and activities on society and the environment, through transparent and ethical behaviour that: 1) contributes to sustainable development, including health and welfare of society; 2) takes into account the expectations of stakeholders; 3) is in compliance with applicable law and consistent with international norms of behaviour* and *4) is integrated throughout the organization"* (ISO 26000, 2010). The International Guidance Standard on Social Responsibility distinguishes between seven categories, called core subjects, that have to be considered by any organization that aims to improve its sustainability performance (Baumgartner, 2019). They comprise Organizational Governance, Human Rights, Labour Practices, Environment, Fair Operating Practices, Consumer Issues, and Community Involvement and Development, which are subdivided into 36 issues (ISO 26000, 2010). Except for the subject "environment", all the others belong to the social dimension of sustainability (Baumgartner, 2019). ISO 26000 is thus designed to assist organizations in contributing to sustainable development, encouraging them to go beyond basic legal compliance, and to promote social responsibility, complementing other instruments and initiatives (GRI & ISO, 2014). According to Messmann et al. (2020), the ISO 26000 is the most frequently cited framework when assessing social sustainability.

In addition to the ISO 26000, there is another international standard: the Social Accountability 8000 (SA 8000). SA 8000 is the world's leading social certification program that encourages organizations to develop, maintain and apply socially acceptable practices in the workplace (SGS, 2020; SAI, 2020). Created by the Social Accountability International (SAI) in 1997, it has led the industry for over 20 years (SAI, 2020). This auditable certification standard was based on international workplace norms of International Labour Organization (ILO) conventions, the Universal Declaration of Human Rights and the UN Convention on the Rights of the Child. Therefore, SA 8000 is mainly focused on the human and labour rights, being available for organizations of any size, in any industry, and in nearly every country of the world (Lozano & Huisingh, 2011). The standard presents a set of criteria and a specific monitoring system that an enterprise needs to comply with in order to be certified (UNEP, 2009). SA 8000 addresses issues including forced and child labour, occupational health and safety, freedom of association and collective bargaining, discrimination, disciplinary practices, working hours, compensation, and management systems (SAI, 2020). One of the main benefits of this certification is to prove commitment to social accountability and to treat employees ethically and in compliance with global standards (SGS, 2020).

Chiarini & Vagnoni (2017) compared SA 8000 and ISO 26000, identifying some differences between CSR implementation by means of each standard, which should be interesting for practitioners who are thinking of implementing a CSR system. According to the authors, ISO 26000 could have a greater effect on the effectiveness of a CSR system from a strategic point of view. On the other side, SA8000 is more based on strategies to ensure compliance with laws and regulations and, consequently, its effect on strategy is not so significant. Even though both standards affect a multi-stakeholder approach, SA8000 seems to be more focused on particular stakeholders such as workers, unions and NGOs, while ISO 26000 takes into account all possible stakeholders. Furthermore, ISO 26000 is perceived to have a more positive relationship with environmental management issues than SA8000. Finally, the article also identifies an interesting and possible integration between ISO 26000 and ISO 14001 standards.

### 3.2.3. Global Reporting Initiative

The Global Reporting Initiative (GRI) is a non-profit organization founded in 1997 in the city of Boston, United States of America (USA). GRI mission is to help organizations to be transparent and take responsibility for their impacts, enabled through a global common language (GRI, 2020). The Sustainability Reporting Guidelines are a long-term, multi-stakeholder and international framework developed by GRI between 2000 and 2013 in versions from GRI G1 to G4. The framework outlines a voluntary structure for annual sustainability reporting, applicable to all types of organizations, being one of its primary goals the stakeholder dialogue (Lozano, 2006). The Guidelines were succeeded by the GRI Sustainability Reporting Standards (GRI, 2020). These frameworks aim at supporting organizations alongside the supply chain in evaluating their performance in all the three pillars of sustainability (Messmann et al., 2020). In addition, they offer a consistent basis for organizational reporting on strategy, management techniques and performance indicators. The focus is thus on a particular organization, rather than on the life cycle of a product (Benoît-Norris et al., 2011). GRI is similar to ISO 26000, in that it seeks to address applications of social sustainability unique to organizations (Sutherland et al., 2016).

The performance indicators are grouped into social, economic, and environmental categories. In the social category, G4 Guidelines proposes a total of 48 indicator measurements which are grouped into four subcategories (GRI, 2013):

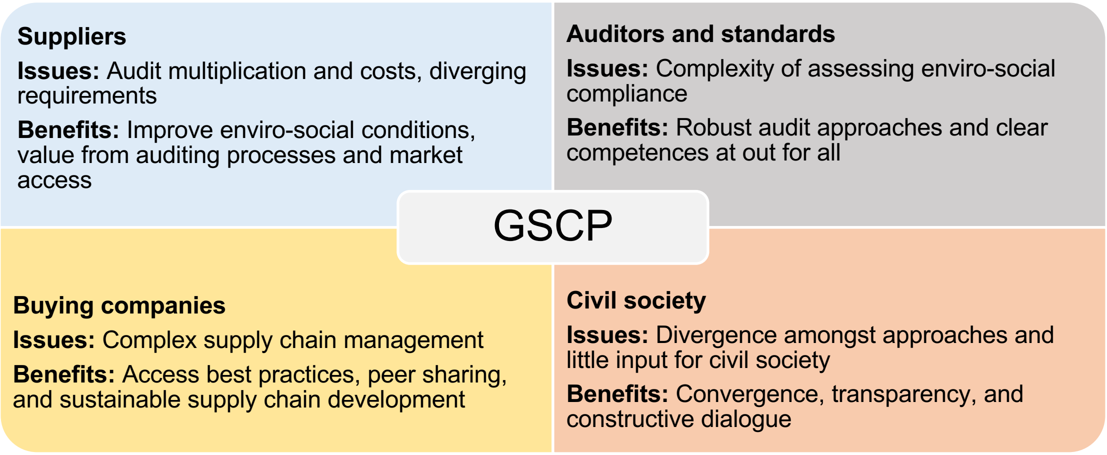
1. Labour Practices and Decent Work (LA) – (16 indicators) addresses several issues such as employment, occupational health and safety, training and education, diversity and equal opportunities, gender discrimination, among others.
2. Human Rights (HR) – (12 indicators) covers aspects like non-discrimination, gender equality, child labour, collective bargaining, freedom of association, among others.
3. Society (S) – (11 indicators) *"concerns the impacts that an organization has on society and local communities"* (GRI, 2013, p. 198), including topics such as corruption, public policy, local communities, among others.
4. Product Responsibility (PR) – (9 indicators) *"concerns the products and services that directly affect stakeholders, and customers in particular"* (GRI, 2013, p. 221), comprising aspects like customer health and safety, marketing communications, customer privacy, among others.

According to Lozano & Huisingh (2011), GRI Guidelines are probably the most widely used and accepted standard to assess, report and disclose sustainability issues by organizations. Although, some authors pointed out the main disadvantages of the GRI framework, as follows: 1) the large number of indicators, which complicates longitudinal comparisons and benchmarking (Lozano, 2006); 2) it can become costly to collect the information for the indicators (Luken & Stares, 2005); 3) it does not consider synergies among the three dimensions (Lozano & Huisingh, 2011); and 4) many of the indicators are qualitative or have a binary condition and, for this reason, it does not allow comparability from year to year (Sutherland et al., 2016).

### 3.2.4. Global Social Compliance Programme

The Global Social Compliance Programme (GSCP) is an initiative of the Consumer Goods Forum and it aims to address the problems of audit fatigue and duplication, audit quality, and unmet expectations in improving social impacts (Benoît-Norris et al., 2011). Created in 2010 by a group of committed companies from various sectors and affiliations, the GSCP's mission is "*to harmonise existing efforts and deliver a common, consistent and global approach across sectors for the continuous improvement of working and environmental conditions in global supply chains*" (UNGC, 2020). Motivated by the conviction that the way forward in sustainability is through collaboration and convergence, major retail companies, international organizations, academia and government, have joined forces within the GSCP framework to deliver a harmonized approach for more efficient and sustainable supply chains (The Consumer Good Forum, 2020). This important work was accomplished through a set of Reference Tools, a robust Equivalence Process benchmark tool and regular meetings and working groups. GSCP Reference Tools are a complete suite of documents compiling best practices for managing sustainable supply chains which are free and open-source. They provide a common interpretation of fair labour/social and environmental requirements and their respective implementation in the supply chain. As a global reference, the tools may be used and adapted to local or sector-specific contexts. On the other hand, the Equivalence Process is a mechanism by which a social/environmental compliance scheme is objectively benchmarked against the requirements defined in GSCP Reference Tools, to determine their level of equivalence (The Consumer Good Forum, 2020). The process enabled users to assess tools and processes, identify any gaps, drive internal alignment, and move towards mutual recognition (UNGC, 2020).

Even though it is less multistakeholder-oriented than ISO 26000 and GRI, the GSCP has delivered a wealth of useful tools for auditing in supply chains. However, GSCP set of tools are more limited since it does not cover positive impacts, which are as important as negative impacts and thus, should be taken into consideration. In addition, while the GSCP focuses on the stakeholder group Workers, and somewhat Value Chain Actors, it does not address the Local Community, Society, and Consumer stakeholder groups (Benoît-Norris et al., 2011). An integration of the technique can be seen in Figure 5.



**Suppliers**

**Issues:** Audit multiplication and costs, diverging requirements

**Benefits:** Improve enviro-social conditions, value from auditing processes and market access

**Auditors and standards**

**Issues:** Complexity of assessing enviro-social compliance

**Benefits:** Robust audit approaches and clear competences at out for all

GSCP

**Buying companies**

**Issues:** Complex supply chain management

**Benefits:** Access best practices, peer sharing, and sustainable supply chain development

**Civil society**

**Issues:** Divergence amongst approaches and little input for civil society

**Benefits:** Convergence, transparency, and constructive dialogue

Figure 5: GSCP approach to collaborative, sustainable global supply chains (Adapted from Shutherland et al., 2016)

### 3.2.5. Social Life Cycle Assessment

In 2004, the United Nations Environmental Programme (UNEP) / Society of Environmental Toxicology and Chemistry (SETAC) life cycle initiative recognized a need on the integration of social criteria into LCA and establish the following main objectives: (1) to convert the current environmental tool LCA into a triple bottom line (3BL) sustainable development tool; (2) to develop a framework for the inclusion of socio-economic benefits into LCA; (3) to determine the implications for life cycle inventory analysis and for life cycle impact assessment; and (4) to provide an international forum for the sharing of experiences with the integration of social aspects into LCA (Benoît et al., 2010). In this sense, the Social LCA (SLCA) was thus created as a part of the full assessment of goods and services within the context of sustainable development (UNEP, 2009). Different approaches have been proposed for the integration of the three pillars, among them the Life Cycle Sustainability Assessment (LCSA), where LCSA= ELCA+LCC+SLCA (Corona et al., 2017). LCSA is considered as the most promising methodology for sustainability assessment, allowing a truly holistic representation of the three pillars of sustainability (Benoît et al., 2010; Souza et al., 2015).

Like ELCA, SLCA not only makes use of industrial ecology modelling and accounting frameworks but also draws from concepts and frameworks from Corporate Social Responsibility (CSR) (Garrido, 2017). In its origins, SLCA was strongly linked to CSR (Jørgensen et al., 2009), but now it is known that SLCA goes beyond CSR, considering all the social and socioeconomic impacts of products along their whole life cycle (Ramos Huarachi et al., 2020). In particular, the ISO 26000 Guidelines for Social Responsibility and the Global Reporting Initiative G3 Guidelines were an important backdrop to SLCA development (Garrido, 2017).

Benoît et al., (2010) defined SLCA as a *“systematic process using best available science to collect best available data on and report about social impacts (positive and negative) in product life cycles from extraction to final disposal”.* Social impacts are consequences of social relations from an activity (production, consumption or disposal) on the well-being of stakeholders (UNEP, 2009). An important achievement in the development of SLCA was the publication of the UNEP/SETAC guidelines and recommendations on how to conduct a Social Life Cycle Assessment of Products (Benoît et al., 2010). The document constitutes a general framework based on two dimensions: stakeholders and impacts categories. The first one refers the “*cluster of stakeholders that are expected to have shared interests due to their similar relationship to the investigated product system*”, and its categories are: Workers; Local Community; Society (national and global); Consumers; and Value chain actors (UNEP, 2009). The second one, the impact categories, are: Human Rights, Working Conditions, Health and Safety, Cultural Heritage, Governance and Socioeconomic Contribution. They are further divided into a total of 31 impact subcategories. Impact subcategories are defined as socially significant themes or attributes, which have been defined according to international agreements and best practices at the international level (UNEP, 2009; Benoît et al., 2010). Subcategories are classified according to stakeholder and impact categories and are assessed by the use of inventory indicators, measured by unit of measurement (or variable) (UNEP, 2009). Subcategories are the basis of a SLCA assessment since they are the items on which justification of inclusion or exclusion needs to be provided (UNEP, 2009). Figure 6 illustrates the relation between these concepts.

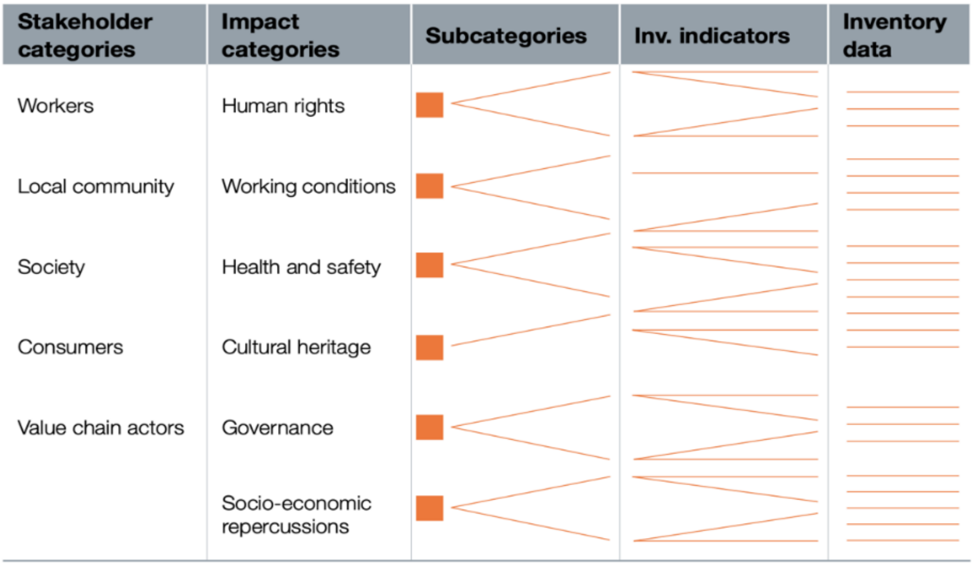


Figure 6: Assessment system from categories to unit of measurement (UNEP, 2009)

The Guidelines were later complemented by the Methodological Sheets for Social LCA, which provide clear and practical measurement guidance for each subcategory by offering examples of inventory indicators, units of measurement, and data sources (Benoît-Norris et al., 2011; Sureau et al., 2018). Table 3 establishes the relation between each stakeholder and its related subcategories of impact.

Table 3: Stakeholder categories and subcategories (UNEP, 2009)

| Stakeholder categories | Subcategories |
|---|---|
| **Stakeholder "worker"** | Freedom of Association and Collective Bargaining<br>Child Labour<br>Fair Salary<br>Working Hours<br>Forced Labour<br>Equal opportunities/Discrimination<br>Health and Safety<br>Social Benefits/Social Security |
| **Stakeholder "consumer"** | Health and Safety<br>Feedback Mechanism<br>Consumer Privacy<br>Transparency<br>End of life responsibility |
| **Stakeholder "local community"** | Access to material resources<br>Access to immaterial resources<br>Delocalization and Migration<br>Cultural Heritage<br>Safe & healthy living conditions<br>Respect of indigenous rights<br>Community engagement<br>Local employment<br>Secure living conditions |
| **Stakeholder "society"** | Public commitments to sustainability issues<br>Contribution to economic development<br>Prevention & mitigation of armed conflicts<br>Technology development<br>Corruption |
| **Value chain actors (not including consumers)** | Fair competition<br>Promoting social responsibility<br>Supplier relationships<br>Respect of intellectual property rights |

SLCA is based on the ELCA and originally, it was conceived as a social complement to ELCA. Both methodologies share the same framework (ISO 14044 framework), comprising four main steps, which are:

1. **Goal and scope definition** – comprises several subjects, including the study's objective, the functional unit (FU), the boundaries of the product system, the stakeholder categories and subcategories included, and evaluation methods (Garrido, 2017). The functional unit is key to LCA and it is based on the product's function for the consumer, allowing quantitative assessment and comparison of impacts (Benoît et al., 2010).
2. **Life cycle inventory analysis (LCI)** – consists in the collection and organization of data, which can be qualitative, quantitative or semiqualitative (Garrido, 2017). Data collection is recognized as a critical factor for the development of SLCA, since it is costly and time demanding (Valente et al., 2018; SHDB, 2019). A typical product system contains several unit processes and thus, it is not practical to collect site-specific data at every organisation along a life cycle, especially considering the increasing globalisation of supply chains (Du et al., 2019). Despite these difficulties, data is typically collected through interviews, questionnaires, literature review or databases, such as the Social Hotspot Database (SHDB) and the Product Social Life Impact Life-Cycle Assessment (PSILCA) (both will be further described in this section).
3. **Impact evaluation (or life cycle impact assessment) (LCIA)** – is the process by which inventory data is aggregated within subcategories and categories. According to the Guidelines, this step is divided into three phases (UNEP, 2009):
   - **3.1. Selection –** the choice of impact categories, subcategories and characterization models, in accordance with the goal and scope of the study.
   - **3.2. Classification –** inventory results are assigned to a specific Stakeholder Category and/or Impact Category.
   - **3.3. Characterization –** ISO 14044 (2006) describes this phase as *"the conversion of LCI results to common units and aggregation of the converted results within the same impact category".* This conversion uses characterization factors, and the outcome of the calculation is a numerical indicator result.
4. **Interpretation –** consists in a set of actions including the identification of significance issues, evaluation of the study, level of engagement with stakeholders and some conclusions or recommendations (UNEP, 2009). The results are typically presented in tables, Graebel diagrams, bar graphs, showing results per life cycle step or impact subcategory or category (Garrido, 2017).

The purpose of Social Life Cycle Assessment is to evaluate the social aspects associated with the life cycle of goods and services, as well as to identify the hotspots of the value chain where social risks may be higher (Corona et al., 2017). SLCA can be used to identify, learn about, communicate, and report social impacts; set up strategies and action plans; inform management policies and purchasing practices; and compare the social impacts between different products (Benoît et al., 2010; Corona et al., 2017). The final results can be applied to improve the social performance of the organisations and therefore, positively influence the well-being of affected stakeholders (Siebert et al., 2018a).

SLCA can be performed applying two different approaches (type I or type II), that differ in terms of impact assessment methods (third step of the SLCA methodology). The first one, also known as “Social Performance SLCA”, seek to aggregate, weight and score inventory indicators in order to compare with Performance Reference Points (PRPs) and determine if societal expectations are whether met, or not. PRPs are typically defined as *“internationally set thresholds, or goals or objectives according to conventions and best practices”* (UNEP 2009, p. 72), which allow to assess either a social performance or a risk of encountering a specific social performance. The second one, also known as “Impact Pathway SLCA”, strive to assess social impacts by establishing a connection between the source of impact and its impact on human well-being, also called impact pathway (UNEP, 2009). As stated by Garrido (2017), impact pathways “*are the chain or causal relations which can be traced between activities and their ultimate social outcomes*”.

Furthermore, two databases have been built in order to support the product system modelling, data collection, evaluation, and weighting (Garrido, 2017). The Social Hotspot Database (SHDB), operated by the US-based not-for-profit organization New Earth, provide practitioners with generic data to identify social hotspots in value chains (Sureau et al., 2018). Social hotspots are production activities in the product life cycle that provide a higher opportunity to address issues of concern (e.g., human and worker rights, community well-being), as well as highlight potential risks of violations or others that need to be considered when doing business in a specific sector and country (Benoit-Norris et al., 2012). SHDB includes information on 160 indicators covering 26 impact subcategories, which were selected from the Guidelines (SHDB, 2019) The other database is the Product Social Impact Life Cycle Assessment (PSILCA), developed by the Germany-based consultancy company Greendelta (Sureau et al., 2018). It provides statistical data for 69 qualitative and quantitative indicators under 25 subcategories from the Guidelines (PSILCA, 2020). To formulate the indicators, several sources were used (Sureau et al., 2018). For every country-specific sector considered in a given product system, both databases will evaluate social data according to levels of social risk. For the impact assessment method, SHDB has four risk levels: from low risk to very high risk, and PSILCA has five levels: from very low risk to very high risk (SHDB, 2019; PSILCA, 2020). Risk levels and their respective characterization factors are represented in Table 4.

Table 4: Characterization factors for Impact assessment method in SHDB (left) and PSILCA (right). (SHDB, 2019; PSILCA, 2020)

| **SHDB** | |
|---|---|
| **Risk level** | **Factor** |
| Very high risk | 10 |
| High risk | 5 |
| Medium risk | 1 |
| Low risk | 0,1 |

| **PSILCA** | |
|---|---|
| **Risk level** | **Factor** |
| Very high risk | 100 |
| High risk | 10 |
| Medium risk | 1 |
| Low risk | 0,1 |
| Very low risk | 0,01 |

The points of reference for the assessment scales vary, but the overall majority are based on how a company, a sector or a country is positioned compared to the worldwide performance. Both databases will link these results with the number of hours worked at each stage of the life cycle, which can be higher or lower depending on the risk level (Norris et al., 2019). Results are thus expressed as worker-hours at a specified level of risk for a given social issue, per dollar of process output. Through a conversion rule, these levels of social risks can also be converted to a single unit (medium risk hours equivalent), which allows overall aggregation of different levels of risk (Garrido, 2017). In the SHDB approach, the scores for the different subcategories (also known as social themes) within each social endpoint category are aggregated into a Social Hotspots Index (SHI), defined by Equation (1) (SHDB, 2016).

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

$SHI_{cat}$ = Social Hotspot Index for a category (e.g., human rights and governance)

$T$ = Social themes (e.g., gender equity and corruption)

$n$ = 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 the theme

Regardless of the number of indicators in each impact category, the larger the value of SHI, the higher are the potential impacts in that category for a country-sector (Du et al., 2019). In this sense, SHI is the impact assessment method of the SHDB, providing users the possibility to quantify social risks, identify social hotspots in the supply chain, and calculate a social footprint (SHDB, 2019).

According to Ramos Huarachi et al. (2020), the SHDB has been the most used SLCA database, being applied in several products and industry sectors. Hence, this database has a great potential in order to standardize SLCA. However, it is important to highlight that, even though SLCA is in its best era and caught the attention of sustainability practitioners, the methodology is still under development stage, remaining as a fragmented filed (Cadena et al., 2019). While many SLCA approaches have been developed, a standard method has yet to be agreed upon and thus, there is still a long way ahead in order to achieve a real standardization (Ramos Huarachi et al., 2020). The major aspects still under discussion with regard to the implementation of SLCA include: (1) indicator selection and analysis (Mathe, 2014); (2) functional unit definition (Macombe et al., 2013); and (3) impact assessment methods (Ekener-Petersen & Finnveden, 2013). Hence, there is neither a standardised nor a straightforward procedure for conducting a SLCA that analyses a particular type of product being produced within a region (Siebert et al., 2018a). In this context, the use of databases, the application and development of Social LCIA methods and quantification frameworks, is absolutely important to achieve that goal. Therefore, it is relevant to know on what studies has SLCA been applied. A summary of the studies published on the literature can be found in Table 5.

Table 5: Selected examples of SLCA application

| Author (Year) | Product system or Industry sector assessed | Study focus and General purposes |
|---|---|---|
| Benoit-Norris et al. (2012) | Strawberry yoghurt | Identifies the social hotspots in the strawberry yoghurt supply chain, using data from the SHDB. |
| Lehmann et al. (2013) | Technologies in water supply and fuel production | Focuses on social issues, discussing the applicability of SLCA guidelines for a comparative technology analysis, taking the example of 2 case studies, extracting data from SHDB. Then, appropriate indicators to address these aspects are identified. |
| Ekener-Petersen & Finnveden (2013) | Laptop Computer | Identifies the location and nature of hotspots in the product system. The final purpose is to test and evaluate the SLCA methodology and to inform policy decision by Government of Belgium. |
| Foolmaun & Ramjeeawon (2013) | PET (polyethylene terephthalate) bottles | Compares the environmental and social impacts of four selected disposal alternatives of used PET bottles. The final objective is to inform policy decision by Government of Mauritius. |
| Macombe et al. (2013) | Biodiesel | Analyses social impacts in LCA at three levels: company, regional and state level. Also, it outlines lines of research that are needed to improve the methodological basis of SLCA. |
| Aparcana & Salhofer (2013) | Recycling system | Comparing social impacts of formalized recycling systems in low-income countries in comparison with informal systems. The main purpose is to develop/refine the SLCA methodology. |
| Ekener-Petersen et al. (2014) | Fossil fuels and biofuels for vehicles | Social and socioeconomic impacts of various biofuels and fossil fuels were screened by applying SLCA methodology. Data were taken from the SHDB. |
| Martínez-Blanco et al. (2014) | Fertilizers | Compares three types of fertilizers, using data from SHDB. The main purpose is to develop/refine the SCLA methodology. |
| Arcese et al. (2017) | Italian wine sector | Supplies a theoretical basis for practical applications in wine sector in Italy that could be generalized as a starting point for SLCA application in another agri-food sector. |
| Chen & Holden (2017) | Dairy farm | Investigates the social impacts of dairy farm via a case study using a SLCA framework. |
| Corona et al. (2017) | Solar Power Plant | Provides additional discussion on the practical application of SLCA by suggesting a new classification and characterization model. The application of this methodology is demonstrated using a case study. |
| Valente et al. (2018) | Bioethanol and biochemical production | Aims to test indicators for assessing the environmental and social impacts of biorefineries. Testing and selecting the most suitable ones contribute to the further development of SLCA methodologies while assessing several dimensions of sustainability at biorefineries. SLCA was performed using SHDB. |
| Di Noi & Ciroth (2018) | Mining sector | Focuses on social and environmental issues in mining. Different methodologies were explored. Then, an ELCA and SLCA, extracting data from PSLICA, were performed, completing results with a literature research. |
| Du et al. (2019) | Sugar cane | Explores how the quality of the results of a screening SLCA can be improved, illustrated by a case study of sugarcane production in Brazil, an activity which has been criticized due to issues such as poor working conditions. Data were extracted from the SHDB |
| Thies et al. (2019) | Lithium-Ion batteries | Analyses the social hotspots in the supply chain, using data from SHDB. The main contribution is to support battery manufacturers and stakeholders in designing socially beneficial supply chains. |
| Cadena et al. (2019) | Biorefinery | Aims to propose a new methodology to SLCA for production process design assessment, using a biorefinery project located in the Netherlands as an example. The methodology will provide an overview of the potential social hotspots found along the biorefinery life cycle. |

To conclude, SLCA has been applied in different products and industries, gaining value as a real technique in sustainability science. In fact, these last years were the greatest for SLCA literature (Ramos Huarachi et al., 2020). As it can be observed in Table 5, the most common purposes when applying a SLCA to a case study are the following: (1) to develop and refine the currently SLCA methodology, proposing new contributions to its further development and improvement; (2) to identify social hotspots along the entire life cycle of the product or industry analysed in the study; and (3) to conduct a comparative analysis of different products regarding their social impacts. Even though the SLCA methodology starts to gain important and has been applied in several industries, there is still no studies with the application of this methodology for the forest sector. Nevertheless, the next section will identify what has been studied on the literature regarding the link between social sustainability and the forest-based industries.

## 3.3. Social sustainability applied to forest-based industries

The previous section has revealed the lack of studies applying the SLCA methodology and its respective databases (SHDB or PSILCA) to the forest-based industries. However, it is important to know what has been explored and studied in the literature about the social dimension of sustainability in the forest sector. The following paragraphs will explain the main contributions regarding this subject.

Vering (2006) studied the connection between the forest and the social sector. The author tries to answer the question of how the forestry sector may contribute to the social integration of marginal groups (e.g., homeless people, long-term unemployed, immigrants). Results from this analysis show that there is a high potential for integration through the forest sector and that these opportunities should be used, promoting a new working field for the forest administration.

According to Slee (2007), interest in social aspects of forestry has grown in the United Kingdom (UK) and Western Europe in recent years. Social aspects of forestry have been a long-term concern in less developed countries where forests have long been identified as an important contributor to livelihoods. In this sense, the author reviews the problems surrounding the development of social indicators for multifunctional forestry in the UK, concluding that social indicators are problematic for several reasons and thus, they have been marginalised and relatively weakly researched. One of the principal challenges to the development of social indicators in forestry is the extent to which multifunctional forestry necessarily engages a wider range of stakeholders. In consequence, the derivation of a consensus as to what might be appropriate indicators can be seen as problematic. A second major difficulty is the identification (and then measurement) of appropriate social indicators. This can be seen as both a problem of objective science (know what to measure but not exactly how to best go about it), or a problem of competing stakeholder values and their legitimation. Thus, there is a widely perceived need in government to assess social performance of forests more objectively and consensually.

In the same year, Sheppard et al. (2007) synthesized some of the main themes of social sustainability indicators for forest management, and addressed conceptual categories, issues and limitations associated with the use of social indicators. The paper illustrated how a selection of social indicators has been prescribed and used within various sustainable forest management systems of criteria and indicators at different scales. Social indicators are, in general, weakly developed relative to ecological and economic indicators. Additionally, commonly used social indicators are often procedural and do not measure salient outcomes. Therefore, to increase public acceptance of forest management decisions, both scientists and managers need to improve their understanding of management outcomes for social values within the context of the people that are affected by these outcomes. Improved knowledge would reduce risks to global market factors and local forest management operations. In addition, it will promote trust and credibility among the various stakeholders.

Siebert et al. (2018a) outlined a new framework that can help to identify, monitor and evaluate the social performance of organisations involved in the production of wood-based products in a German bioeconomy region, concluding that the framework requires a high level of detail in the social inventory and impact assessment phase. Despite this, the framework can be used to develop a SLCA method to accurately analyse a product's social performance from a regional perspective in order to inform decision makers about improving or preventing social effects caused by their production activities. Later, the same authors proposed a set of indices and indicators to monitor the social implications of wood-based products, which are compatible with the framework established in the previously work (Siebert et al., 2018b). This was done in four steps: 1) screening of global, German and wood related sustainability standards (e.g., GRI, ISO 26000, SA 8000, FSC); 2) analysis of SLCA case studies; 3) conducting of stakeholder interviews. To set up the final set of social indices and indicators, the preselected sets of social aspects, in a fourth step, were further screened regarding their feasible implementation. The established set provides a starting point for assessing and monitoring social implications from wood-based production systems in a regional foreground.

After analysing the existing literature about social sustainability in the forest sector, it became clear that it is necessary a deepen research concerning this field, due to the following reasons: (1) social indicators are problematic and thus, need to be properly identified, developed and quantified in the forest sector; (2) there is still no studies applying the SLCA methodology proposed by the Guidelines; (3) the use of databases, such as SHDB and PSILCA, have not yet been applied in the forest sector; and finally, (4) the number of studies concerning the forest sector and the social dimension of sustainability are still not enough to extract solid conclusions. Therefore, this constitutes good reasons to explore, evaluate and quantify the social impacts in the forest sector, through a Social LCA methodology combined with one of its two databases (SHDB or PSILCA).

## 3.4. Chapter conclusions and problem statement

Two main literature gaps have been identified in this study. First, the social dimension of sustainability remains poorly explored, less standardized and quantified, when compared to the other two dimensions (economic and environmental). Second, there is lack of studies regarding the assessment of the social sustainability of the forest sector and its forest-based industries. Furthermore, there is still no studies applying the Social LCA methodology proposed by the Guidelines, as well as its two suggested databases (SHDB and PSILCA) to forest-wood products. Nevertheless, since the forest sector provides numerous benefits for the society and contributes for the creation of several jobs, it is important to study this dimension, as well as to evaluate and monitor the social impacts (both positive and negative) along its entire supply chain. In this sense, the future research aims to study and quantify the social and socioeconomic impacts of the forest sector, identifying possible improvements and areas of concern. For the purpose of this study, the forest sector will be represented by the three most manufactured products from each major Portuguese forest-based industry, which are the uncoated woodfree (UWF) paper from the pulp and paper industry, natural cork stoppers from the cork industry, and particle boards from the wood industry. Accordingly, the Social Life Cycle Assessment (SLCA) will be the selected methodology for the future work since it is the most effective technique to assess and quantify social impacts of products throughout their entire life cycles. Additionally, data will be extracted from the Social Hotspot Database (SHDB), since it is the most applied database in case studies and thus, having a great potential to standardize the SLCA methodology (Ramos Huarachi et al., 2020).

The results of this analysis can be used to improve the social performance of the companies operating in the forest sector and therefore, positively influence the well-being of affected stakeholders. Moreover, the comparison of results between three different products (uncoated woodfree paper, natural cork stoppers and particle boards) will allow to determine the best performance, from a social perspective, and this information can then be used by governments to support policy decisions about improving the social effects caused by their production activities. Moreover, since the concept of sustainability comprises three dimensions (social, economic and environmental), conclusions about the other two pillars should also be discussed, in order to determine the product with the greatest overall sustainability performance.

All these problems will be further analysed in detail in the following chapters. The next section presents the research methodology process applied in this study, which is mainly based on the four steps of the SLCA methodology suggested by the Guidelines. Every step of the methodology will be detailed described in the next chapter.

# 4. Research Methodology

This chapter presents the research methodology applied in this work. The purpose of Social Life Cycle Assessment is to evaluate the social aspects associated with the life cycle of goods and services, as well as to identify the hotspots of the value chain where social risks may be higher (Corona et al., 2017).

The UNEP/SETAC has been the main proponent and developer of SLCA procedures. Despite being at a development stage, its *"Guidelines for Social Life Cycle Assessment of Products"* has become a landmark in the field (Corona et al., 2017). According to Chen & Holden (2017), more than 70% of SLCA studies are based on the Guidelines. Therefore, this work will also follow the methodology proposed by the Guidelines, which draws largely on standard ELCA methodology ISO 14040 and 14044, consisting of four interconnected phases (UNEP, 2009). Figure 7 represents the research methodology applied in this study. The first main step consists of the application of the SLCA methodology to the three forest-based industries, comprising four inherent sub-steps. The second step corresponds to the social comparison of the three systems that will be studied in this research. Finally, the last step contains an overall sustainability assessment of each system considering the three dimensions of sustainability. This chapter is organized according to these steps, including an explanation of each step and how they were applied to the three case studies. Assumptions regarding the data collection for the life cycle inventory analysis step will also be discussed in this chapter.

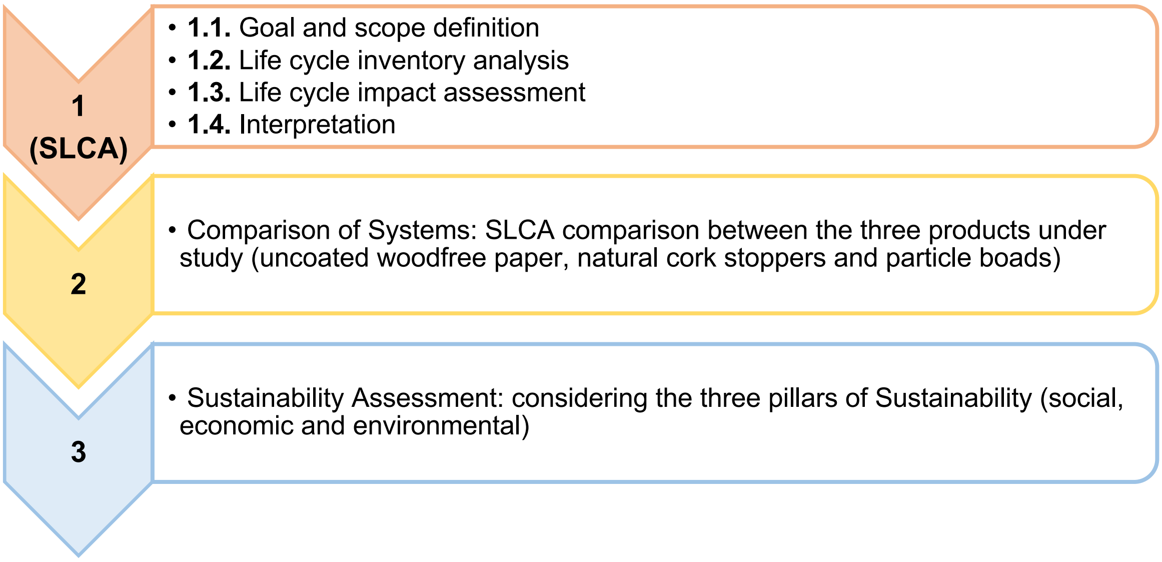


Figure 7: Research methodology steps

**Step 1.1 – Goal and scope definition**

The first step in a SLCA study, Goal and Scope definition, aims of establishing the study's objective and characterizing the system(s) under study through the definition of the functional unit and activity variable, the boundaries of the system(s) considered, the stakeholders and impact subcategories included, and the evaluation and data collection methods selected for the future work.

The functional unit provides a point of reference to quantify the magnitude of the system associated with the product considered, and allows a comparison of different products providing the same/similar purposes (Garrido, 2017). Wherever possible, social impacts are related to the functional unit defined for the product under study. However, since social issues are mainly related to the activities and procedures of the companies involved in the provision of the goods/services, and also to other nonquantitative social aspects, processes may not be associated with a physical functional unit, but with an activity variable that reflects the share of a given activity associated with each unit process (Corona et al., 2017). The activity variable is a variable representing a quantifiable activity that can be measured at each life cycle step (or process) (Garrido, 2017). This variable is proportional to the output in each process and, therefore, to the functional unit previously defined (Martínez-Blanco et al., 2014). The Guidelines suggest two different activity variables: added value and working time, being the last one the most frequently used (Garrido 2017; UNEP, 2009). For this reason, the activity variable that will be used in this study is working time. Furthermore, the SHDB which will be applied in this work, uses working time, expressed in work hours, as activity variable (SHDB, 2019).

The main goal of this study is to evaluate the potential social impacts caused by the forest sector, which will be represented by the life cycle of the three most manufactured products from each major Portuguese forest-based industry. In addition, one of the objectives for conducting this research through the SLCA is to determine the best use, from a social point of view, that can be given to land between the plantation of *Eucalyptus globulus* to produce uncoated woodfree paper, the plantation of *Quercus suber* to produce natural cork stoppers, and the plantation of *Pinus pinaster* to produce particle boards. The research findings will offer a context for developing strategies to improve the social performance of the Portuguese companies operating in the forest sector. Moreover, since the selected products for this study are the most manufactured ones from each major Portuguese forest-based industry, they will serve as a preliminary representation of the forest sector as a whole. Therefore, conclusions about the social sustainability of the forest sector will be formulated in this research, and a set of recommendations for different stakeholders (e.g., government and private companies) will be provided, to help them prioritizing their efforts in reducing the social impacts throughout the life cycle of the forest products.

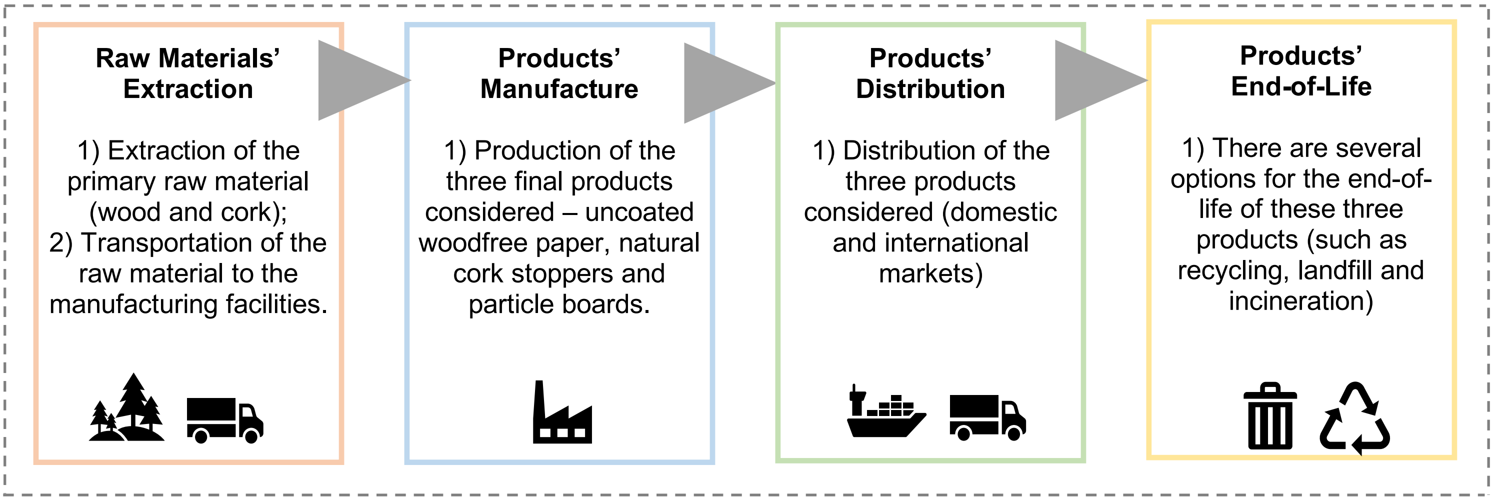
The three systems that will be analysed and compared in this research are described as:

- **System 1** - Uncoated woodfree paper manufacture from *Eucalyptus globulus* (Portucel, 2012):
  Product: Uncoated Woodfree paper
  Size: A4 (210 x 297 mm)
  Grammage: 80g/m2 (Navigator Universal paper)
  Thickness: 110 micrometres
  Moisture: 4%
- **System 2** - Natural cork stoppers manufacture from *Quercus suber* (APCOR, 2015):
  Product: Natural cork stoppers
  Size: diameter (24 ± 0,5) mm; length (45 ± 1) mm
  Shape: Cylindric
  Density: 160kg/m3 – 220kg/m3
  Moisture: 4% – 9%

- **System 3** - Particle boards manufacture from *Pinus pinaster* (McNatt, 1974; Rivela et al., 2006)
  Product: Particle boards
  Size: 2440 x 1220 mm
  Thickness: 12 mm
  Density: 650kg/m3 – 750kg/m3
  Moisture: 6% – 9%

In a comparative LCA, which is the case of this study, the functional unit selected must allow valid comparisons. Since the three products under study have different functions and are used for different purposes, identifying a functional unit in this research is not an easy task. Nevertheless, the products selected are all forest wood products, and thus, they share the same primary raw material, which is wood from different tree species. Moreover, one of the main objectives of this research is to identify the best use, from a social point of view, that can be given to land if the goal was to produce forest wood products. For this reason, the functional unit selected in this project will be the exploration of one hectare of forest land in Portugal for 100 years. It is important to refer that the utilization of 1 hectare of forest land in Portugal for 100 years will result in different quantities of forest wood products, since the number of trees that can be planted per hectare is different for each of the three species considered (depending on their volume, size, diameter). Furthermore, each tree species has a different recommended rotation period (i.e., time between each harvest) and is capable of generating different amounts of wood per harvest (Santos et al., 2021). In this sense, the next Section will identify the quantities of each product assessed in this project.

In order to compare results between the three case studies, the same system boundary must be considered for each of the systems under study. The final products are very different at each life cycle and thus, a cradle-to-grave boundary was selected. This boundary typically includes five main life cycle stages, which are: (1) Raw Materials' Extraction; (2) Products' Manufacture; (3) Products' Distribution; (4) Products' Use; and (5) Products' End-of-Life (PRé Sustainability, 2020). However, the life cycle considered in this study contains four main life cycle stages, since none of the three products have consumptions in terms of the usage stage (Products' Use). The life cycle modelled and the system boundary for the three products is represented in Figure 8.


**Raw Materials' Extraction**

1) Extraction of the primary raw material (wood and cork);
2) Transportation of the raw material to the manufacturing facilities.

**Products' Manufacture**

1) Production of the three final products considered – uncoated woodfree paper, natural cork stoppers and particle boards.

**Products' Distribution**

1) Distribution of the three products considered (domestic and international markets)

**Products' End-of-Life**

1) There are several options for the end-of-life of these three products (such as recycling, landfill and incineration)

Figure 8: Life cycle modelled for the three systems

Table 6 summarizes the most important information of the first step of the research methodology, Goal and Scope definition.

Table 6: Important information of the first step of the SLCA methodology

| | |
|---|---|
| **Products** | Uncoated woodfree paper from *Eucalyptus Globulus* (System 1), Natural cork stoppers from *Quercus Suber* (System 2) and Particle Boards from *Pinus Pinaster* (System 3) |
| **Functional Unit** | The exploration of 1 hectare of forest land in Portugal for 100 years |
| **Activity variable** | Hours of work (SHDB activity variable) |
| **System's boundary** | Cradle-to-grave |
| **Life cycle** | 4 main life cycle stages (represented in Figure 8) |

### Step 1.2 – Life cycle inventory

This step aims to collect and organize the data required for the following steps. Data is typically collected through questionnaires, literature review, existing instruments (monitoring results or audits), and/or databases (Garrido, 2017). The application of databases can simplify this task significantly by revealing where in the supply chain attention should be focused, so called Social Hotspots (Valente et al., 2018). Social hotspots are unit processes located in a region where a social theme of interest may be considered a problem, a risk, or an opportunity (UNEP, 2009). The SHDB is one of the first databases in SLCA which can be utilized as a screening or prioritization tool to analyse and identify these social hotspots (Benoit-Norris et al., 2012). This database seeks to provide access to best available social risk and opportunity information at the most granular level possible, as well as to provide methods and tools to calculate and summarize this information into a quantitative assessment of the social performance across a product life cycle. It uses a multi-regional input-output model that is based on the Global Trade Analysis Project (GTAP) (Thies et al., 2019). The work hours (activity variable) are estimated from GTAP data on wage payments within each region and industry sector. Thus, the SHDB can be used to identify how many work hours are involved for each unit process in the supply chain for a given final demand (Thies et al., 2019). The SHDB has been the most applied database in SLCA studies (Ramos Huarachi et al., 2020). Therefore, it will be the selected database for this research. In order to apply the SHDB, the following information is required (SHDB, 2019):

**1.** A list of all the processes' inputs (such as chemicals, energy, water) used to manufacture the three products under study, which are uncoated woodfree paper, natural cork stoppers and particle boards.

**2.** Which of the 57 Global Trade Analysis Project (GTAP) sectors the processes' inputs belong to (GTAP model contains trade data for 57 economic sectors and 140 countries and regions).

**3.** In which country were the processes' inputs sourced from, as well as the respective percentage that is produced in the country where the life cycle is taking place (in this study, the life cycle takes place in Portugal and thus, it is necessary to know the domestic production of this country for each input material). The information related with the countries of origin (only imports) was collected from the Atlas of Economic Complexity (Growth Lab of Harvard University, 2018) and a cut-off rule was applied: only countries that contributed more than 1% to the total imports of each input were considered. The domestic production of Portugal for each input material was sourced from literature review, statistics platforms and reports of relevant activities and identities, being justified in Table 23 of Appendix B. Both the domestic production percentage and the import percentage can be seen in Table 24 of Appendix B.

**4.** What is the cost of the processes' inputs. The cost of each item was converted to USD of the year 2011 (SHDB unit). To obtain the prices of each material input, assumptions have to be made. The process behind getting the price of each inventory input is divided into three different groups (Chemical, Forest and Utilities Inputs), since each group follows different assumptions and justifications. The process to obtain the prices of these inputs are justified in Table 25 of Appendix B.

### **4.1.** Chemical Inputs

Spain is the main supplier of chemical products to Portugal, representing about 30% of the total imports of the country, followed by Germany and The Netherlands. Even though China became the world's largest chemical producer, the imports from this country to Portugal only represent 2% of the total chemicals' imports. Essentially, most of the imported chemicals to Portugal come from the European Union (EU) (Cefic, 2020). According to a report from Eurostat (2020), the second most tradable and exported good within the EU are chemicals and chemicals products. Sosvilla-Rivero & Gil-Pareja (2004) stated that *"empirical evidence is obtained on price convergence for tradable goods"*. In addition, *"the speed of convergence rises with the tradability of the product"* (European Commission, 2007). Therefore, in order to simplify the data collection process in this research, chemical prices were assumed to not vary significantly and thus, the same price was considered between the different countries where the chemical products were sourced from. The same approach was used in the article proposed by Thies et al. (2019), in which variations in price between countries were considered to not be significant.

Whenever possible, the price of each chemical was obtained contacting directly with companies selling their chemicals to the Portuguese industry. Notice that, for large quantities, chemicals' prices are much lower than for fewer quantities. In this research, the price considered is usually related with the minimum quantity sold by the company assessed (typically 25 kg of product), allowing a worst-case scenario.

### **4.2.** Forest Inputs

The functional unit defined in the first step of the research methodology is the exploration of one hectare of forest land in Portugal for 100 years. In this sense, the forest inputs required (pulpwood, cork and roundwood) have 100% Portuguese origin and thus, the prices correspond to the Portuguese market. The prices of the forest inputs were taken from a Table of ICNF, the Portuguese Institute for Nature and Conservation of Forests (ICNF, 2020).

### **4.3.** Utilities Inputs

As it was explained previously in this section, the whole life cycle of the three products under study take place in Portugal and thus, the Products' Manufacture stage also occurs in this country. Therefore, the prices of the different utilities (e.g., energy, water, natural gas, diesel) used in the production process correspond to the Portuguese prices. These prices were taken from different sources, such as statistics platforms (pordata, statista) and websites of relevant activities (such as EPAL – group of waters in Portugal).

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

### Step 1.3 – Life cycle impact assessment

The Guidelines define LCIA as being *"the phase of a SLCA that aim at understanding and evaluating the magnitude and significance of the potential impacts for a product system throughout the life cycle of the product"* (UNEP, 2009). In this step, the use of a software is helpful in order to convert the data collected in the previous step into social impacts. Data is weighted using characterization factors, and then aggregated for interpretation (Garrido, 2017).

There are two different types of Social LCIA methods: Type I and Type II SLCA, also known, respectively, as "Social Performance SLCA" and "Impact Pathway SLCA". This study follows a Type I approach, a decision that has been based on the complexity and lack of information regarding social cause-effect relationships for the forest sector (UNEP, 2009; Corona et al., 2017). Furthermore, the SHDB, which will be applied in this study, contains an impact assessment method, called Social Hotspot Index (SHI), which belongs to the Type I SLCA. The different types of SLCIA methods (Type I and Type II) and the calculation of the SHI are explained in detail in subsection 3.2 of the present document.

The three systems were modelled using a LCA software, namely SimaPro version 9.1.1. This software is compatible with the selected database (SHDB) and the assessment method chosen is the Social Hotspot 2019 Subcategories & Categories Method with Damages (where the different subcategories are weighted equally). This choice was based on a recommendation by the PRé Consultancy (PRé Sustainability, 2019). The method has five categories: (1) Labour Rights and Decent Work; (2) Health and Safety; (3) Human Rights; (4) Governance; and (5) Community (see Table 7). Each category covers a range of relevant subcategories of impact (also known as social themes), with one or more indicators to measure the risk level of each theme for a country-sector. The social themes were selected based on the Guidelines (SHDB, 2016).

The labour intensity information is used together with the social risks, to express social risks and opportunities in terms of medium risk hours equivalent (Mrheq), by economic sector and country for 5 of the 6 main categories of impact. The risk indicators represent a qualitative assessment of risks, but the combination with labour intensities introduces quantitative data that allow for aggregation across processes. In the characterization phase of impact assessment, the different risk categories are expressed relative to the medium risk level by multiplying them with respective characterization factors, representing the relative probability of an adverse situation to occur (Thies et al., 2019). The expression of social impacts in medium hours equivalent (Mrheq) allows the possibility to calculate a social footprint and to identify target areas in their supply chains to improve social conditions (SHDB, 2019).

Table 7: Impact categories and social themes considered in the method (SHDB, 2019)

| Impact Categories | Impact Subcategories (or social themes) |
|---|---|
| **Labour Rights & Decent Work** | Forced Labour (FL)<br>Excessive Working Time (EWT)<br>Poverty (P)<br>Freedom of Association (FoA)<br>Wage Assessment (W)<br>Migrant Labour (ML)<br>Unemployment (U)<br>Child Labour (CL)<br>Labour Laws Conventions (LLC)<br>Discrimination (D)<br>Social Benefits (SB) |
| **Health & Safety** | Injuries and Fatalities (IF)<br>Occupational Toxics and Hazards (OTH) |
| **Human Rights** | Indigenous Rights (IR)<br>Human Health Issues – Communicable Diseases (CD)<br>Human Health Issues ─ Non-communicable Diseases (NCD)<br>Gender Equity (GE)<br>High Conflict Zones (HCZ) |
| **Governance** | Legal System (LS)<br>Corruptions (C) |
| **Community** | Assess to Hospital Beds (AHB)<br>Assess to Drinking Water (ADW)<br>Assess to Sanitation (AS)<br>Children Out of School (CoS)<br>Smallholder vs. Commercial farms (SCF) |

### Step 1.4 – Interpretation

This last step of the SLCA methodology concerns the process of assessing results obtained in the previous step in order to draw conclusions. The results obtained from the SLCA can be analyzed in several ways and thus, this step is still not standardized and varies from one study to another (Garrido, 2017; Thies et al., 2019). This research will mainly identify:

- Critical impact categories: the ones which have a higher contribution on the single score of each system;
- Critical impact subcategories: the ones which have the higher share of worker hours. The Pareto analysis, also known as "80/20" rule is a useful tool to identify these subcategories (Carvalho et al., 2014). This principle states that 80% of effects arise from 20% of the causes;
- Critical life cycle processes: It is important to identify which of the processes have a higher impact on the life cycle of the products under study, in order to take actions and strategies to

improve the social performance. These processes are the ones which contribute more for the critical subcategories identified in the previously analysis;

- Social hotspots: to identify the activities (or inputs) that are located in a region where a situation occurs that may be considered a problem, a risk or an opportunity, in relation to a social theme of interest.

The interpretation will focus on explaining these results, discuss root causes and propose recommendations for the problems identified, which should be aligned with the study's initial objective. Furthermore, limitations regarding the data collection and the SLCA methodology will also be identified and explained in this step. In addition, a sensitivity analysis will be conducted to understand how the results of this study are affected by the uncertainty of the input data used.

**Step 2 – Comparison of systems**

This step of the methodology aims to compare the results of the three systems under study. The final objective for conducting this research is to understand what the better forest specie (*Eucalyptus globus, Quercus Suber* or *Pinus Pinaster*) from a social point of view is, if it was necessary to plant 1 hectare of land in Portugal with one of these three species. Accordingly, each forest specie is represented by the most manufactured product that can be obtain using this specie as raw material. Furthermore, the main conclusions about the forest sector will be given, since the three selected products (natural cork stoppers, uncoated woodfree paper and particle boards) represent a high share of manufactured products in this sector.

The comparison between these three systems will be based on:

- Midpoint level: the first comparison between the three case studies is performed at the midpoint level. The characterized values of the different impact subcategories will be analysed, in order to identify which of the system under study hast the least characterized values. In addition, the normalized values of the different subcategories will be compared, to identify the most critical subcategories for each system, as well as for the forest sector in general.
- Endpoint level: secondly, a comparison at the endpoint level is performed. The five endpoint categories are compared to identify what are the most critical categories for the three systems and thus, for the forest sector in general.
- Overall social impact: lastly, the Single Score (SS) of the three life cycles in terms of absolute value is compared. In addition, the SS per kilogram (kg) of product manufactured and per Net Present Value (NPV) generated by selling the previous quantity will also be compared. As it will be discussed in the next step, the NPV value was retrieved from Santos et al. (2021).

The focus of this work is to evaluate the social impacts of the Portuguese forest sector. However, since the sustainability concept comprises three interconnected dimensions, conclusions about the other two pillars (economic and environmental) should also be discussed and analysed. The next step of the research methodology will assess these three products in terms of their overall sustainability performance, considering the three dimensions.

**Step 3 – Sustainability Assessment**

The last step of the research methodology aims to formulate conclusions about the three systems and its respective products in terms of their overall sustainability performance. The concept of sustainability comprises three different dimensions: social, economic and environmental. When all the three dimensions are satisfied over the long term, this can be thought of as being sustainable (Sutherland et al., 2016). In this sense, it is important to assess the other two dimensions, in order to formulate solid conclusions about their sustainability performance. For this purpose, the work proposed by Santos et al. (2021), which focused on the assessment of the economic and the environmental pillars of these three products, will be used to complement the present study. If possible, the most sustainable product would be selected. The choice of this product will be based on the following Equation (2):

$$Sustainability\ Ratio\ (kPt/euro^2) = \frac{SS_{social}}{NPV} \times \frac{SS_{environemntal}}{NPV} \tag{2}$$

$SS_{social}$ = Single Score of the SLCA application (kPt)

$SS_{environmental}$ = Single Score of the ELCA application (kPt)

$NPV$ = Net present value (euro)

The most sustainable product will be the one with the best performance in the three dimensions of sustainability, which means that:

- Both social and economic impacts, expressed by the SS obtained in the SLCA and ELCA, respectively, should be the least and therefore, the numerator of the two terms expressed in Equation (2) must be minimized.
- The NPV obtained for each system should be the greatest and thus, the denominator of Equation (2) must be maximized.

Considering the previous points, one can conclude that the most sustainable product will be the one with the lowest Sustainability Ratio identified in Equation (2), since the numerator is minimized, and at the same time, the denominator is maximized.

Except for the first step, Goal and scope definition, which has been completely characterized in this section, the application and discussion of the five last steps of the research methodology (life cycle inventory, life cycle impact assessment, interpretation, comparison of systems and sustainability assessment) will be presented in the next section.

# 5. Results analysis and Discussion

This chapter is divided into three main sections. Section 5.1 presents the SLCA methodology applied to the three different products under study. This section contains three subsections which corresponds to the three last steps of the SLCA methodology. Then, a comparison between the three systems is performed in Section 5.2 and the main conclusions about the forest sector will also discussed in this section. Lastly, Section 5.3 aims to assess the three systems in terms of their overall sustainability performance considering the three sustainability dimensions, and the most sustainable product will be selected.

## 5.1. Step 1 – SLCA Application

This subsection consists of the SLCA application to the three systems under study (Step 1 of the Research methodology). In this subsection, the last three sub-steps of the SLCA methodology (Step 1.2 to 1.4) will be applied to each system, corresponding to subsections 5.1.1 to 5.1.3.

### 5.1.1. Step 1.2 – Life cycle inventory

In order to collect the data required, as well as to model these three systems for the next step, it is firstly necessary to determine: (1) the amount of pulpwood, cork and roundwood that could be harvest from 1 ha of forest land in Portugal planted with *Eucalyptus globulus*, *Quercus suber* and *Pinus pinaster*, respectively, given a time horizon of 100 years; and (2) the quantity of each product (UWF paper, natural cork stoppers and particle boards) that can be manufacture using the amount of raw materials (wood and cork) identified in the previous step. Accordingly, Table 8 summarizes all the quantities necessary to model these three systems. These values were retrieved from the article presented by Santos et al., (2021), which were used to model the environmental and economic assessment of these three products.

Table 8: Amount of raw material harvested from 1 ha of forest land in Portugal for 100 years with each specie and quantity of product obtained using the amount of raw material previously calculated (Santos et al., 2021)

| | **Quantity** | **Unit** | **Life cycle stage** |
|---|---|---|---|
| **System 1** | | | |
| Pulpwood | 1721.43 | cubic meters | Raw Materials' Extraction |
| Uncoated woodfree paper | 529840.41 | kilograms | Products' Manufacture |
| **System 2** | | | |
| Cork | 14649.29 | kilograms | Raw Materials' Extraction |
| Natural cork stoppers | 2929.86 | kilograms | Products' Manufacture |
| **System 3** | | | |
| Roundwood | 382.01 | cubic meters | Raw Materials' Extraction |
| Particle board | 223.72 | cubic meters | Products' Manufacture |

The remaining of this substep 1.2, Life cycle inventory, is organised according to the four life cycle stages identified in the previous section: (1) Raw Materials' Extraction, (2) Products' Manufacture, (3) Products' Distribution, and (4) Products' End-of-life. Each stage includes a brief description and a summarized table with the inventory data required to model each life cycle stage in the LCA software.

The inventory data presented in each table for both the Raw Materials' Extraction and Products' Manufacture stages is composed by all the inputs required to model the stage in question as well as its respective quantities, GTAP sectors, prices per unit and total price (in USD 2011), and the domestic production and import percentage of the different inputs. The assumptions made to obtain the values from Table 9 to Table 16 are all justified in Appendix B of the present document.

### (1) Raw Materials' Extraction

The first life cycle stage consists of extracting the primary raw material used in the three systems - wood (Systems 1 and 3) and cork (System 2). This stage also includes the respective transportation of the raw material to the facility where the final product is manufactured.

#### System 1

The amount of pulpwood that could be harvest from 1 ha of forest land in Portugal planted with *Eucalyptus globulus* is 1721.43 cubic meters (see Table 8).

In order to calculate the distance of transportation between the regions where the raw material is harvested and the facilities where the product is manufactured, some assumptions have to be made. *Eucalyptus globulus* trees exist in 23 different subregions of mainland Portugal, being more common in the *Região de Coimbra* subregion (ICNF, 2015). Table 27 of Appendix C presents the quantity and share of *Eucalyptus globulus* trees that exist in these different subregions. These shares were multiplied by the total volume of pulpwood (1721.43 cubic meters) to determine the quantity of pulpwood provided by each subregion. The same approach was used in Santos et al. (2021), to study the environmental impacts (ELCA). For example, from the total of 845.01 thousand hectares of *Eucalyptus globulus* in mainland Portugal, 119.58 (14.15%) thousand hectares are located in the *Região de Coimbra* subregion. Consequently, it was considered that 243.61 cubic meters of pulpwood (see Table 28 in Appendix C) were sourced from this subregion, which corresponds to 14.15% of the total pulpwood volume (1721.43 cubic meters). Since most companies that manufacture UWF paper in Portugal are located in the *Região de Coimbra* subregion (INE, 2018a), it was assumed in this study that this was where the UWF paper is manufactured. The distance from the 23 subregions and the *Região de Coimbra* subregion was considered to be the distance between where the raw material is extracted and the facility where the product is manufactured.

The inventory data for this stage is represented in Table 9. The column "Total Price" was obtained multiplying the price per unit by its respective quantity necessary to manufacture the amount of product identified (529840.41 kg). Notice that pulpwood is usually harvested using a machine (chainsaws) that consumes both diesel and lubricating oil.

Table 9: Inventory data of System 1 for the Raw Materials' Extraction stage

| | Quantity | Unit | Price per Unit (USD 2011) | Total Price (USD 2011) | GTAP Sector | National Production Percentage | Import Percentage |
|---|---|---|---|---|---|---|---|
| Pulpwood | 1721.4 | m3 | 20.6336 | 35519.4 | frs | 100.0% | 0.0% |
| Diesel | 111548.9 | MJ | 0.0321 | 3582.8 | p_c | 0.0% | 100.0% |
| Lubricating oil | 516.4 | kg | 8.6482 | 4466.2 | chm | 39.4% | 60.6% |
| Transport (lorry) | 195782578.2 | kgkm | 0.0002 | 39156.5 | otp | 0.0% | 100.0% |

## System 2

The amount of cork that could be harvest from 1 ha of forest land in Portugal planted with *Quercus Suber* is 14649.29 kilograms (see Table 8).

The same procedure of System 1 was applied to calculate the distance of transportation between the regions where the cork is extracted and the facilities where the natural cork stoppers are produced. *Quercus suber* trees exist in different subregions of mainland Portugal being more common in the *Alentejo Central* subregion. Table 27 in Appendix C presents the quantity and share of *Quercus suber* trees that exist in the 23 different subregions of mainland Portugal (ICNF, 2015). These shares were used together with the quantity of cork previously calculated (14649.29 kg) to determine the amount of cork provided by each of the 23 subregions (see Table 28 in Appendix C), as explained for System 1. It was assumed in this study that the natural cork stoppers are produced in the *Área Metropolitana do Porto* subregion since this is where most companies that manufacture this product in Portugal are located (INE, 2018a). The distance from the 23 subregions where the cork was sourced and the *Área* Metropolitana *do Porto* subregion was considered to be the transportation input included in Table 10. Contrary to System 1, this stage of the life cycle does not include diesel nor lubricating oil as inputs, since the stripping of cork is usually done manually (Santos et al., 2021).

Table 10: Inventory data of System 2 for the Raw Materials' Extraction stage

| | Quantity | Unit | Price per Unit (USD 2011) | Total Price (USD 2011) | GTAP Sector | National Production Percentage | Import Percentage |
|---|---|---|---|---|---|---|---|
| Cork | 14649.3 | kg | 1.5078 | 22088.2 | frs | 100.0% | 0.0% |
| Transport (lorry) | 5145082.0 | kgkm | 0.0002 | 1029.0 | otp | 0.0% | 100.0% |

## System 3

The amount of roundwood that could be harvest from 1 ha of forest land in Portugal planted with *Pinus Pinaster* is 382.01 cubic meters (see Table 8).

*Pinus pinasters* trees exist in different subregions of mainland Portugal being more common in the *Região de Coimbra* subregion. Table 27 in Appendix C presents the quantity and share of *Pinus pinasters trees* that exist in the 23 different subregions of mainland Portugal (ICNF, 2015). These shares were used together with the volume of roundwood previously calculated (382.01 cubic meters) to determine the volume of roundwood provided by each of the 23 subregions (see Table 28 in Appendix C) (Santos et al., 2021). The distance of transportation between the subregions where the roundwood is harvested and the facilities was calculated applying the same procedure as for the other two systems. Since most companies that produce particle boards are located in the *Viseu Dão Lafões* subregion (INE, 2018a), it was assumed in this study that this is where the product is manufactured. The distance from the 23 subregions where the roundwood was sourced and the *Viseu Dão Lafões* subregion was considered to be the transportation input included in Table 11. As for System 1, both diesel and lubricating oil were included in Table 11 since roundwood is usually harvested using machines.

Table 11: Inventory data of System 3 for the Raw Materials' Extraction stage

| | **Quantity** | **Unit** | **Price per Unit (USD 2011)** | **Total Price (USD 2011)** | **GTAP Sector** | **National Production Percentage** | **Import Percentage** |
|---|---|---|---|---|---|---|---|
| Roundwood | 382.0 | $m^3$ | 25.6928 | 9815.0 | frs | 100.0% | 0.0% |
| Diesel | 6019.2 | MJ | 0.0321 | 193.3 | p_c | 0.0% | 100.0% |
| Lubricating oil | 48.6 | kg | 8.6482 | 420.4 | chm | 39.4% | 60.6% |
| Transport (lorry) | 28674024.3 | kgkm | 0.0002 | 5734.8 | otp | 0.0% | 100.0% |

### (2) Products' Manufacture

The second life cycle stage consists in the production of the three products considered, which are uncoated woodfree paper (System 1), natural cork stoppers (System 2), and particle boards (System 3).

#### System 1

The production of uncoated woodfree paper starts with growing and harvesting the trees. Then, each tree's trunk is bucked into logs, which are delivered to mills where they are debarked and chipped. The next stage is pulp production, and the purpose of this stage is to separate the cellulose fibers from the other wood components such as lignin (the "glue" that cements the fibers together), extractives (e.g., fats, waxes, and alcohols), minerals and other inorganics. For this separation, chemical methods are the most effective and thus, the pulp obtained using these methods is not considered wood since most of the other wood components are removed in this process. This explains why uncoated woodfree paper, manufactured using chemical pulp, is known as woodfree. The most common chemical method is the Kraft (sulfate) method in which the wood chips are pressure-cooked with water and chemicals, sodium hydroxide and sodium sulfide, in a digester. The resulting pulp is screened to remove uncooked wood and washed to remove the spent cooking mixture. Depending on the final product, the pulp can be bleached (using chlorine dioxide, oxygen, or hydrogen peroxide) after being produced, due to the brown coloration of the raw pulp caused by the presence of lignin that was not removed during cooking. The next stage consists of transforming the wood pulp into a continuous sheet by injecting this pulp onto a vibrating rolling wire screen mat where the fibers are interlock into sheets and the water drains. After the compression between a long series of rollers, followed by steam-heated dryers where most of the remaining moisture is removed, large sheets of dry paper are obtained and wounded onto rolls that can be cut in different sizes to produce a variety of papers (Santos et al., 2021).

The quantity of UWF paper that can be manufactured from the amount of pulpwood that could be harvest from 1 ha of forest land in Portugal planted with *Eucalyptus globulus* given a time horizon of 100 years is 529840,41 kilograms (see Table 8). Table 12 contains all the inventory data related with the production of this final product. However, there is another step-process before this one, which is the production of the sulfate pulp, and this process is represented in Table 29 of Appendix C.

Table 12: Inventory data of System 1 for the Products' Manufacture stage (UWF paper)

| | Quantity | Unit | Price per Unit (USD 2011) | Total Price (USD 2011) | GTAP Sector | National Production Percentage | Import Percentage |
|---|---|---|---|---|---|---|---|
| Alkylketene dimer sizing agent | 1059.7 | kg | 1.858 | 1968.5 | chm | 39.4% | 60.6% |
| Carbon dioxide (liquid) | 604.0 | kg | 0.155 | 93.5 | chm | 39.4% | 60.6% |
| Electricity | 212042.1 | kWh | 0.121 | 25657.1 | ely | 91.7% | 8.3% |
| Hard coal | 3719.5 | kg | 0.066 | 245.5 | coa | 0.0% | 100.0% |
| Heavy fuel oil | 14941.5 | kg | 0.776 | 11591.6 | p_c | 0.0% | 100.0% |
| Hydrogen peroxide | 2241.2 | kg | 0.339 | 759.1 | chm | 39.4% | 60.6% |
| Kaolin | 63051.0 | kg | 1.980 | 124853.6 | nmm | 39.4% | 60.6% |
| Lignite briquettes | 41804.4 | MJ | 0.033 | 1379.5 | coa | 0.0% | 100.0% |
| Lime | 63051.0 | kg | 0.062 | 3902.9 | nmm | 39.4% | 60.6% |
| Magnesium sulfate | 1298.1 | kg | 1.011 | 1312.9 | chm | 39.4% | 60.6% |
| Methanol | 662.3 | kg | 1.156 | 765.5 | chm | 39.4% | 60.6% |
| Natural gas (high pressure) | 22688.0 | m3 | 1.218 | 27629.5 | gas | 0.0% | 100.0% |
| Nitrogen (liquid) | 68.9 | kg | 0.155 | 10.7 | chm | 39.4% | 60.6% |
| Oxygen (liquid) | 7099.9 | kg | 0.155 | 1099.1 | chm | 39.4% | 60.6% |
| Potato starch | 20133.9 | kg | 3.922 | 78957.2 | chm | 39.4% | 60.6% |
| Quicklime | 2633.3 | kg | 0.111 | 292.3 | nmm | 39.4% | 60.6% |
| Sodium chlorate | 7576.7 | kg | 2.517 | 19067.6 | chm | 39.4% | 60.6% |
| Sodium chloride | 121.9 | kg | 3.715 | 452.7 | chm | 39.4% | 60.6% |
| Sodium hydroxide | 11497.5 | kg | 1.135 | 13052.0 | chm | 39.4% | 60.6% |
| Sulfur dioxide | 604.0 | kg | 3.612 | 2181.7 | chm | 39.4% | 60.6% |
| Sulfuric acid | 9219.2 | kg | 2.012 | 18552.8 | chm | 39.4% | 60.6% |
| Water | 45036.4 | m3 | 1.804 | 81254.7 | wtr | 100.0% | 0.0% |

**System 2**

The production of natural cork stoppers starts with stripping the cork manually from the *Quercus suber* trees. Then, the cork planks are cooked in boiling water to clean the cork, to extract water-soluble substances, to increase the thickness and, lastly, to make the cork more softer and elastic. After boiling, a period of stabilization occurs, in which the cork planks are left at open-air for about six months until they reach the moisture content (around 14%) necessary for processing. The planks are then separated into quality categories and cut into strips that are perforated with a drill, to obtain a cylindrical stopper. The waste obtained in this process can be used for cork granulate to produce a wide range of different products. After obtaining the cylindric shape, the cork stoppers are rectified to regularize its surface and reach the specified dimensions. The next operation is the selection, where finished stoppers are separated into different grades, and defective stoppers are eliminated and do not move on in the process. Usually, using hydrogen peroxide or peracetic acid, the stoppers are washed in order to be disinfected. The final stage is marking the natural cork stoppers according to customers' specifications and treating the surface with paraffin or silicon to make the stopper easier to insert and extract from the bottle (APCOR, 2021; Santos et al., 2021).

The quantity of natural cork stoppers that can be manufactured from the amount of cork that could be harvest from 1 ha of forest land in Portugal planted with *Quercus suber* given a time horizon of 100 years is 2929.86 kilograms (see Table 8).

Table 13 contains the inventory data related with the natural cork stoppers finishing stage. Notice that there are two other step-processes before this one (the manufacture of cork planks and the natural cork stoppers production), being both presented in Table 30 and 31 of Appendix C.

Table 13: Inventory data of System 2 for the Products' Manufacture stage (natural cork stoppers finishing)

| | **Quantity** | **Unit** | **Price per Unit (USD 2011)** | **Total Price (USD 2011)** | **GTAP Sector** | **National Production Percentage** | **Import Percentage** |
|---|---|---|---|---|---|---|---|
| Electricity | 1579.6 | kWh | 0.121 | 191.1 | ely | 91.7% | 8.3% |
| Printing ink | 0.4 | kg | 0.155 | 0.6 | chm | 39.4% | 60.6% |
| Polydimethylsiloxane | 8.8 | kg | 0.121 | 117.6 | chm | 39.4% | 60.6% |
| Paraffin | 43.2 | kg | 0.066 | 71.4 | chm | 39.4% | 60.6% |
| Sulfur dioxide | 2.9 | kg | 0.776 | 10.6 | chm | 39.4% | 60.6% |

**System 3**

The manufacturing of particle board starts with the growing and harvesting of the trees. The trunk of each tree is then bucked into logs, debarked, and cut into small chips. These chips are further reduced in size, which can be accomplished using several different ways, such as using a hammer mill. The next stage consists in reducing the moisture content of the wood particles using a dryer. Once the wood particles have been dried, they are sprayed with adhesive resin, and its dosage play a key role in the stability of the final board. The most common used resins are urea formaldehyde, melamine formaldehyde, or phenol-formaldehyde, being the first one the cheapest and easiest adhesive to use (Rivela et al., 2006). Then, a particle mattress consisting of the face and core layers is formed. Usually, the core of the board consists of large particles and the face layers consist of finer particles, allowing improved surface finish. The particle mattress is then pressed at high temperatures using either a continuous or batch process. The last stage consists of sanding, adding any coating or lacquers, and cutting to size the boards (Irle, 2010; Santos et al., 2021)

As it can be seen in Table 8, a total of 223.72 cubic meters of particle boards can be produced with the volume of roundwood (382.01 cubic meters) that is generated by 1 ha of forest land in Portugal planted with *Pinus pinaster* given a time horizon of 100 years.

Table 14 contains all the necessary inputs (quantity, price, GTAP sector and share of domestic production) to model this stage.

Table 14: Inventory data of System 3 for the Products' Manufacture stage

| | **Quantity** | **Unit** | **Price per Unit (USD 2011)** | **Total Price (USD 2011)** | **GTAP Sector** | **National Production Percentage** | **Import Percentage** |
|---|---|---|---|---|---|---|---|
| Aluminum sulfate | 346.3 | kg | 1.75 | 607.6 | chm | 39.4% | 60.6% |
| Electricity | 23006.0 | kWh | 0.12 | 2783.7 | ely | 91.7% | 8.3% |
| Natural gas (Heat) | 44012.4 | MJ | 0.04 | 1549.1 | gas | 0.0% | 100.0% |
| Heavy fuel oil (Heat) | 5525.3 | MJ | 0.02 | 99.7 | p_c | 0.0% | 100.0% |
| Light fuel oil (Heat) | 4977.0 | MJ | 0.03 | 167.6 | p_c | 0.0% | 100.0% |
| Lubricating oil (Heat) | 55.6 | kg | 8.65 | 480.9 | chm | 39.4% | 60.6% |
| Melamine formaldehyde resin | 2183.3 | kg | 1.74 | 3796.6 | chm | 39.4% | 60.6% |
| Methylene diphenyl diisocyanate | 713.0 | kg | 4.61 | 3289.1 | chm | 39.4% | 60.6% |
| Paraffin | 668.7 | kg | 1.65 | 1104.2 | chm | 39.4% | 60.6% |
| Phenolic resin | 267.9 | kg | 2.79 | 746.6 | chm | 39.4% | 60.6% |
| Urea formaldehyde resin | 9920.2 | kg | 2.99 | 29689.1 | chm | 39.4% | 60.6% |
| Urea, as N | 43.2 | kg | 1.31 | 56.7 | chm | 39.4% | 60.6% |
| Water | 53.2 | m3 | 1.80 | 96.0 | wtr | 100.0% | 0.0% |

**(3) Products' Distribution**

The third life-cycle stage consists of distributing the three final products considered. Therefore, it is necessary to determine: (1) the quantity of each product that are distributed to the national and international market; and (2) the distances travelled to guarantee this distribution. The values used in this study to model this stage of the life cycle follows the same approach as the values obtained in the article written by Santos et al. (2021), which were collected from the Portuguese National Statistical Institute (INE, 2018b) and the Food and Agriculture Organization of the United Nations (FAO, 2017). The quantity of each product distributed to the national and international market is represented in Table 15. For example, for System 1, 92% of the UWF paper produced in Portugal and imported to this country is exported to the international market (487953.6 kg) and the remaining 8% (41886.8 kg) stays in Portugal (Santos et al., 2021).

Table 15: Inventory data required to model the Products' Distribution stage for the three systems

| | Percentage | Quantity | Transportation mode |
|---|---|---|---|
| **System 1** | | | |
| Total | 100% | 529840.4 kg | - |
| Domestic Market | 8% | 41886.8 kg | Road |
| International Market | 92% | 487953.6 kg | Road and maritime |
| **System 2** | | | |
| Total | 100% | 2929.9 kg | - |
| Domestic Market | 92% | 2685.8 kg | Road |
| International Market | 8% | 244.1 kg | Road and maritime |
| **System 3** | | | |
| Total | 100% | 223.7 $m^3$ | - |
| Domestic Market | 58% | 129.9 $m^3$ | Road |
| International Market | 42% | 93.8 $m^3$ | Road and maritime |

For the domestic market, 23 points of demand were considered which correspond to the 23 subregions where the raw material (wood and cork) is harvested. The demand of each subregion was assumed to be proportional to the population of each subregion and the transportation mode considered for the domestic market distribution was road, namely Heavy-duty vehicles (HDV). Table 32 of Appendix C represents the contribution share of each subregion and the transportation distances. Meanwhile, for the international market, it was first necessary to determine the countries to which the three forest wood products are exported. Once again, the Atlas of Economic Complexity (Growth Lab of Harvard University, 2018) was used, and only countries that contributed more than 1% to the total exports of each product were considered (Santos et al., 2021). These countries and their relative contribution are presented in Table 33 to 35 of Appendix C. Both road and maritime transportation were considered for the distribution in the international market.

**(4) Products' End-of-Life**

The final life cycle stage consists in the end-of-life phase of the products considered (uncoated woodfree paper, natural cork stoppers and particle boards). There are three different destinations for the end-of-life stage of these products, which are: (1) recycling; (2) incineration (combusted with energy recovery); and (3) landfill. Therefore, it is firstly necessary to determine each product's amount that goes to each end-of-life destination. The percentage and quantity presented in Table 16 were retrieved from the article proposed by Santos et al., (2021). The GTAP sector, "wtr", includes *"water supply, sewerage, waste management and remediation activities"* (GTAP, 2021). The end-of-life stage was considered to take place in the respective countries where the product is sold, both in domestic and international markets (where the product is exported). The prices of each end-of-life destination are justified in Table 26 of Appendix B. Notice that, for System 3, it was assumed that 1 m3 of particle boards weights, approximately, 675kg (Santos et al., 2021).

Table 16: Inventory data required to model the Products' End-of-Life stage for the three systems

| | Percentage | Quantity | End-of-Life cost per unit (USD 2011) | GTAP Sector |
|---|---|---|---|---|
| **System 1** | | | | |
| Recycling | 65.9% | 349164.83 kg | 0.101 | wtr |
| Incineration | 6.7% | 35499.31 kg | 0.039 | wtr |
| Landfill | 27.4% | 145176.27 kg | 0.056 | wtr |
| **System 2** | | | | |
| Recycling | 16.7% | 489.29 kg | 0.051 | wtr |
| Incineration | 15.8% | 462.92 kg | 0.039 | wtr |
| Landfill | 67.5% | 1977.65 kg | 0.056 | wtr |
| **System 3** | | | | |
| Recycling | 16.7% | 37.36 $m^3$ | 34.150 | wtr |
| Incineration | 15.8% | 35.35 $m^3$ | 26.323 | wtr |
| Landfill | 67.5% | 151.01 $m^3$ | 37.605 | wtr |

### 5.1.2. Step 1.3 – Life cycle impact assessment

In the third step of the SLCA methodology, Life Cycle Impact Assessment, the inventory collected in the previous step is converted into social impacts using LCIA methods. The conversion into social impacts allows to aggregate different impacts for the entire supply chain, helping highlight potential hotspots. As mentioned in the Section 4 of the present document, the method selected is the Social Hotspot 2019 Subcategories & Categories Method with Damages, in which all the subcategories are weighted equally.

Table 17 represents the characterized values for all the subcategories included in the method for each of the three systems under study. These values are expressed in two different forms: (1) total values considering the functional unit defined, which is the exploration of 1 ha of forest land in Portugal for 100 years; and (2) values per kg of manufactured product using the amount of raw material obtained through the functional unit selected. Notice that all the subcategories share the same unit of measurement, which is medium risk work hours equivalent (Mrheq).

Table 17: Characterized values for all the subcategories considered for the three systems

| Impact Subcategory (Mrheq) | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|
| | Total | Per kg | Total | Per kg | Total | Per kg |
| **1A Wage** | 78642 | 0,15 | 2502 | 0,85 | 9898 | 0,07 |
| **1B Poverty** | 147623 | 0,28 | 2846 | 0,97 | 17562 | 0,12 |
| **1D Child Labour** | 137854 | 0,26 | 3021 | 1,03 | 18102 | 0,12 |
| **1E Forced Labour** | 207994 | 0,39 | 4178 | 1,43 | 23212 | 0,15 |
| **1F Excessive Working Time** | 200518 | 0,38 | 2555 | 0,87 | 19979 | 0,13 |
| **1G Freedom of Association** | 307723 | 0,58 | 5723 | 1,95 | 34469 | 0,23 |
| **1H Migrant Labour** | 405766 | 0,77 | 12200 | 4,16 | 43438 | 0,29 |
| **1I Social Benefits** | 108600 | 0,20 | 1248 | 0,43 | 10923 | 0,07 |
| **1J Labor Laws/Conventions** | 70546 | 0,13 | 1117 | 0,38 | 7747 | 0,05 |
| **1K Discrimination** | 179435 | 0,34 | 3453 | 1,18 | 21477 | 0,14 |
| **1L Unemployment** | 126496 | 0,24 | 2617 | 0,89 | 18478 | 0,12 |

Table 17: Characterized values for all the subcategories considered for the three systems (Continuation)

| Impact Subcategory (Mrheq) | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|
| | Total | Per kg | Total | Per kg | Total | Per kg |
| **2A Occupational Toxic & Hazards** | 241077 | 0,46 | 6912 | 2,36 | 27044 | 0,18 |
| **2B Injuries & Fatalities** | 349126 | 0,66 | 8707 | 2,97 | 33717 | 0,22 |
| **3A Indigenous Rights** | 84605 | 0,16 | 1576 | 0,54 | 9606 | 0,06 |
| **3B Gender Equity** | 119973 | 0,23 | 2427 | 0,83 | 12977 | 0,09 |
| **3C High Conflict Zones** | 222846 | 0,42 | 4408 | 1,50 | 27757 | 0,18 |
| **3D Non-Communicable Diseases** | 49624 | 0,09 | 988 | 0,34 | 5696 | 0,04 |
| **3E Communicable Diseases** | 88742 | 0,17 | 2197 | 0,75 | 10965 | 0,07 |
| **4A Legal System** | 129146 | 0,24 | 1837 | 0,63 | 14795 | 0,10 |
| **4B Corruption** | 222167 | 0,42 | 4092 | 1,40 | 26224 | 0,17 |
| **5A Access to Drinking Water** | 73271 | 0,14 | 2037 | 0,70 | 10078 | 0,07 |
| **5B Access to Sanitation** | 106913 | 0,20 | 3033 | 1,04 | 13190 | 0,09 |
| **5C Children out of School** | 174776 | 0,33 | 4702 | 1,60 | 20558 | 0,14 |
| **5D Access to Hospital Beds** | 193633 | 0,37 | 4271 | 1,46 | 20027 | 0,13 |
| **5E Smallholder vs Commercial Farms** | 146722 | 0,28 | 4484 | 1,53 | 17202 | 0,11 |

Before interpreting the results from Table 17, it is important to identify the impact categories and subcategories responsible for most of the overall social impact in each system. All the subcategories included in Table 17 share the same unit, which is Mrheq. However, each process is different in its risks (e.g., ethanol in Portugal vs. ethanol in Turkey vs. diesel in Brazil, etc.) and each supply chain has different levels of output from each process (Norris et al., 2019). In this context, it can be difficult to identify which risks are most important. However, one way for comparing and selecting the most critical subcategories is by using normalized (or weighted) values, and the Pareto analysis can be used as an approach for this identification (Carvalho et al., 2014). In this sense, the next subsection will identify the most critical categories and subcategories for the three systems, conduct an interpretation of the results obtained and give recommendations for the companies operating in each industry to improve their social performance. In addition, a sensitivity analysis will be conducted in this subsection to understand how the results of this study are affected by the uncertainty of the input data used.

### 5.1.3. Step 1.4 – Interpretation

The last step of an LCA study, Results Interpretation, consists of interpreting the study results obtained. This interpretation will be based on the identification of the most critical impact categories and subcategories, critical life cycle stages and inputs, and the suggestion of potential alterations to accomplish a reduction in the overall social impacts of each system. In addition, a sensitivity analysis will be conducted in this section.

#### 5.1.3.1. System 1 – Uncoated woodfree paper

The interpretation of the results obtained through the LCA software starts with identifying the most critical impact categories. The SHDB covers different subcategories of impact (also known as social themes) which are aggregated into five main categories, which are: (1) Labour Rights & Decent Work; (2) Health & Safety; (3) Human Rights; (4) Governance; and (5) Community. The contribution of each category to the single score of System 1 is represented in Figure 9.

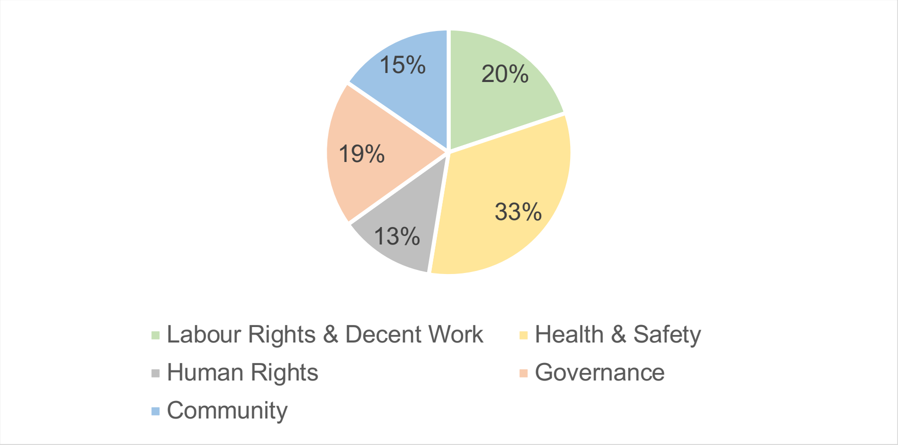


Figure 9: Contribution of each category to the single score of System 1

From the analysis of Figure 9, it is possible to conclude that more than a half percent of the total single score of System 1 (53%) is from impacts concerning both the Health & Safety of workers and the Labour Rights & Decent Work. The first category, Health & Safety, should aim for the following: (1) the promotion and maintenance of the highest degree of physical, mental, and social well-being of workers in all occupations; (2) the prevention among workers of departures from health caused by their working conditions; and (3) the protection of workers in their employment from risks resulting from factors adverse to health (Valente et al., 2018). The main causes for concern among the Health & Safety of workers in the pulp and paper industry are biological agents and chemical compounds in the form of dust or gases. In addition, troubles related to shift work, such as reduced attentiveness, or inadequate supply of blood to the heart, have come into focus (UNECE & FAO, 2003). The second category, Labour Rights & Decent Work, consists of four interrelated and inseparable strategic objectives: (1) full and productive employment; (2) fundamental principles and rights at work; (3) social protection (social security and labour protection); and (4) promotion of social dialogue (ILO, 2008). In this sense, one starting point to improve the social performance of companies operating in the pulp and paper industry should be based on the previous mentioned objectives.

After determining the most critical categories, it is important to identify the impact subcategories which have a higher contribution on the total single score of this system. Accordingly, a Pareto analysis considering the normalized values of the different impact subcategories was conducted to determine the most critical ones. The result of this analysis is presented Figure 10.

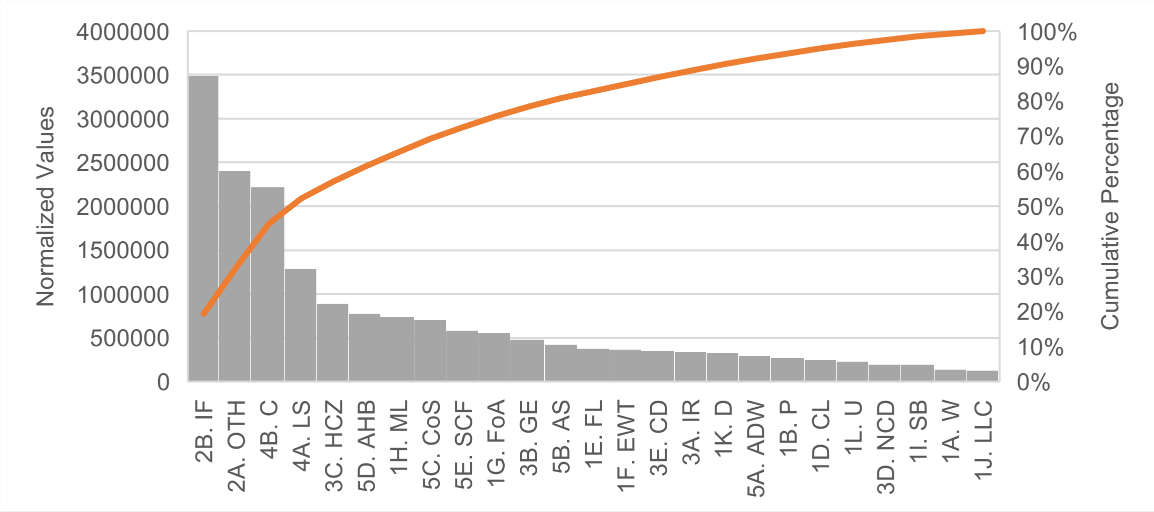


Figure 10: Pareto analysis considering the normalized values of the different subcategories in System 1

From the analysis of Figure 10, it is possible to conclude that the most impactful subcategories and the ones which contribute to, approximately, 80% of the overall social impacts are the: Injuries & Fatalities (IF), Occupational Toxic & Hazards (OTH), Corruption (C), Legal System (LS), High Conflict Zones (HCZ), Assess to Hospital Beds (AHB), Migrant Labour (ML), Children out of School (CoS), Smallholder vs. Commercial Farms (SCF) and, lastly, Freedom of Association (FoA).

The number of subcategories contributing to around 80% of the total single score of System 1 is an extensive list, and the last five subcategories do not have a significant contribution to the overall social impacts in this system (see Figure 10). Therefore, a detailed analysis will be conducted to the first five subcategories which contribute the most to the overall social impacts in this system, corresponding to 20% of the total number of subcategories included in the SHDB. The same approach will be further applied for the other two systems. Firstly, it is important to determine which life cycle stage contributes the most to the social impacts of each critical subcategory. This analysis will help to identify social hotspots in the life cycle of the uncoated woodfree paper, in order to determine where improvements should be done and where the attention should be assigned. Furthermore, by finding this stage, more specific and informed recommendations for the companies in this industry to reduce their social impacts can be provided. Figure 11 presents the contribution of each life cycle stage to the five most impactful subcategories for System 1.

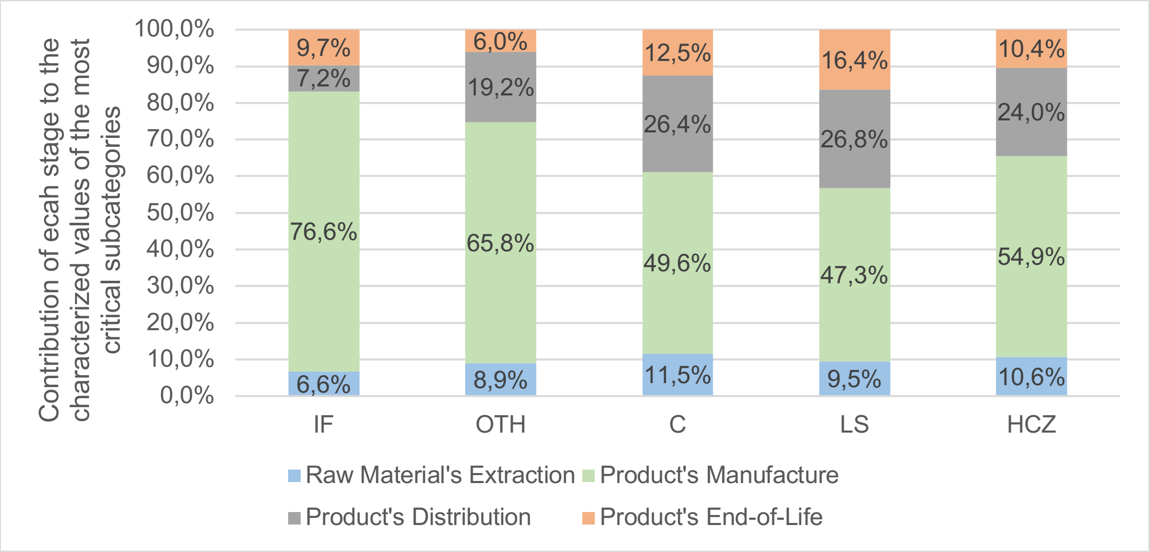


Figure 11: Contribution of each life cycle stage to the characterized values of the five most critical subcategories for System 1

As it can be observed from Figure 11, the Product's Manufacture is the life cycle process that contributes more to the social impacts of all these subcategories. Especially in the most impactful subcategory, Injuries & Fatalities (IF), this life cycle stage has the highest share of contribution, representing 76.6% of the total social impacts of this subcategory. Notice that the production of uncoated woodfree paper involves adding a variety of different pollutant chemicals and, at the same time, a huge consumption of resources (such as energy and water). In fact, the pulp and paper industry is the biggest industrial water user, consuming around 11% of all freshwater in industrial nations (EPN, 2007; WWF, 2020). Further, due to the varieties of pollutants used in the pulping process, around 85% of the water consumed in the paper production industry results in large quantities of contaminated water, which requires advance wastewater treatment solutions in order to be reused (Boguniewicz-Zabłocka & Kłosok-Bazan, 2020). As a result, this may lead to disputes about water resources and its effect on water quality (EPN, 2007). Furthermore, pulp and paper manufacturing is among the world's most energy-intensive industries, and the largest share of greenhouse gases comes from the energy production to power the mills (WWF, 2020). Besides the large consumption of resources, the paper industry is responsible for the release of persistent toxic pollutants (e.g., chlorine) into the environment, resulting in a legacy of health problems including cancers, disorders and fertility problems (EPN, 2007). The most common bleaching agents used by the pulp and paper industry, chlorine and its derivatives (e.g., chlorine dioxide), are quite harmful for the environment and society, producing some of the most toxic compounds on Earth (dioxins and furans). In this sense, it is important to start using alternatives to chlorine for bleaching, such as hydrogen peroxide, which is much safer and are the basis to produce Processed Chlorine Free (PCF) paper (EPN, 2007). In short, the pulp and paper manufacture has been known for its high pollution to air, water and soil, which has negative impacts on the environment and, at the same time, on the society, threatening the health of paper company workers and the communities downstream from mills. Notice that, despite being two distinct dimensions, the social and environmental pillars of sustainability are correlated since the pollution of the environment affects the well-being and health of the society. Therefore, this explains why the Product's Manufacture stage of UWF paper has the highest social impact in the five subcategories analysed, and thus, this life cycle stage will be study further in detail, in order to determine the most critical inputs.

The second life cycle process with the highest contribution in the IF subcategory is the Product's End-of-Life, representing almost 10% of the total social impacts of this subcategory, which means that this stage has risks of occurring injuries and accidents at the workplace. According to the Federal Institute of Occupational Health & Safety (2012), during the treatment of paper, both hazardous substances and biological agents (i.e., microorganisms) may arise at the workplace, which can lead to an intense pollution in the air. These microorganisms are introduced into the process with organic contaminants, and they can be a hazard to the health of workers when airborne (i.e., as a dust constituent), and as smear infection or in the form of fungal disorders of the skin. In addition, it is possible that there will be contaminants from the use, transport, and storage of paper, also in the form of dust constituents. Therefore, it is important to guarantee the right and safe conditions to the workers operating in the paper treatment installations and give appropriate equipment to protect them, such as, for example, respirator masks with particle filters (BAuA, 2012).

Regarding the other four subcategories (OTH, C, LS and HCZ), the second life cycle stage with the highest contribution is the Product's Distribution stage. Especially in the Corruption (C) and Legal System (LS) subcategories, this life cycle stage has the highest share, representing 26.4% and 26.8% of the total characterized value in each subcategory, respectively. According to Chen et al. (2020), transportation is one of the more corruption-prone sectors, largely due to the dimensions and complexity of the construction projects on which it can be difficult to impose adequate and consistent quality control, as well as evaluation measures. Further, since most infrastructure projects require official government approval, the sector tends to be dominated by a small number of monopolistic firms with close links to government officials (Chen et al., 2020). Therefore, this explains why this stage of the life cycle has a higher contribution on these subcategories (C and LS), which both belong to the Governance category.

Since the Product's Manufacture stage has the greatest contribution in the five subcategories analysed (see Figure 11), this stage is the one which requires more attention and where improvements should be done firstly. In this sense, it is important to understand which inputs contribute the most to the negative social impacts of the Product's Manufacture stage in each critical subcategory, before suggesting recommendations. Accordingly, Figure 12 represents the contribution share of the main inputs to the characterized values of the five most critical subcategories identified previously.

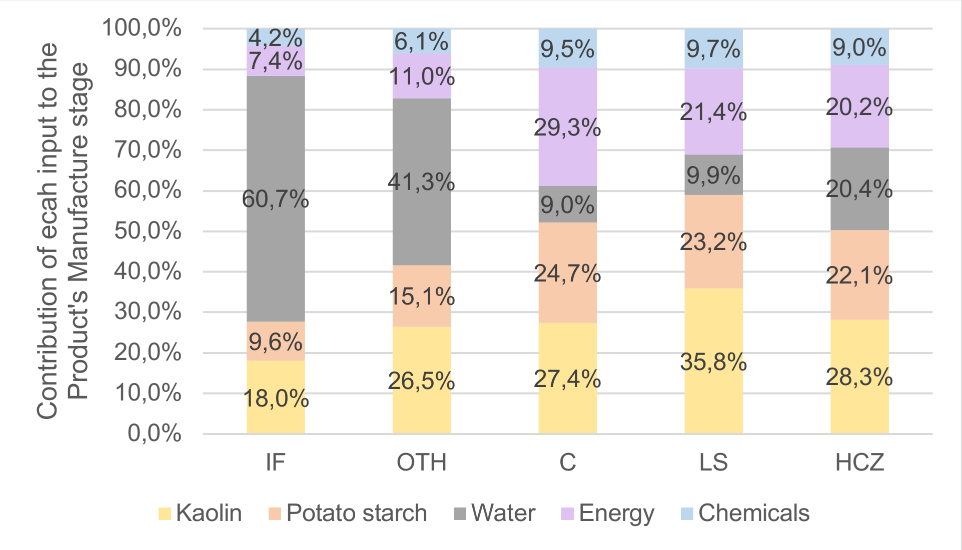


Figure 12: Contribution of the main inputs of the Product's Manufacture to the characterized values of the five most critical subcategories in System 1

In the most impactful category (IF), it is possible to observe from Figure 12 that the consumption of Water is the input with the greatest contribution, representing 60.7% of the total characterized value of this subcategory. The Injuries & Fatalities (IF) subcategory represents an accident arising in the course of employment that may result in death, personal injury, or disease that involves loss of working time. The assessment of this subcategory in the SHDB is based on two data indicators: Accident Rate and Fatality Rate in a country-specific sector (SHDB, 2019). In this study, the Water input was assumed to be sourced from Portugal, since the production stage (where the water is included) takes place in this country. Therefore, one can conclude that workers in the Portuguese water treatment industry are at an increased risk of serious injuries and fatalities. In fact, a research study performed by DEKRA Organizational Safety & Reliability (2018), a global leader in workplace safety, reveals that the utilities sector is the industry of higher risk for serious injuries and fatalities (SIF), being water the most critical utility (having 42% for SIF exposure rate), followed by electricity (32%) and gas (29%). In this sense, it is important to integrate interventions into existing processes, such as implementing safety rules, training, and incident handling systems in the Water treatment industry (DEKRA, 2018). In the second most critical subcategory, Occupational Toxic & Hazards (OTH), the Water input is once again the most critical one, representing 41.3% of the total characterized value of this subcategory. The OTH subcategory is related with the potentially harmful chemicals that are exposed at work, which can have negative impacts on the overall health of workers. This subcategory assesses the risk of toxic noise levels, risk of occupational carcinogens and airborne particulates and risk of contracting diseases (SHDB, 2019). According to ILO (2009), water treatment operators are exposure to high levels of noise from electro-mechanical equipment and to various disinfectants intended for disinfection of water (toxic substances). In addition, psychological stress and pressure may occur due to different factors: annoying noise, water splashing, odours, or high humidity. Therefore, several preventive measures should be adopted by the Portuguese water treatment organisations, such as: (1) use appropriate ear protection and appropriate clothes that fit the climate conditions; (2) check air quality and, if it is necessary, exhaust ventilation before entering in a confined space; (3) apply chemical safety rules when handling or working with hazardous chemicals; and (4) all chemical supply connection points must be checked and appropriate signs must be posted at these points (ILO, 2009).

Then, in third most impactful subcategory, Corruption (C), the input with the highest contribution is Energy, corresponding to 29.3% of the total characterized value of this subcategory. The C subcategory assesses the country’s risk of corruption, and typically include bribery, extortion, cronyism, bias, patronage, and embezzlement (SHDB, 2019). Due to its complex mix of public and private actors and often enshrined centres of monopoly power, the energy sector is prone to corruption. According to Lovei & McKechnie (2000), transparency in the energy industry can be improved by privatizing electricity distribution, where most theft takes place. In addition, electricity customers must be encouraged to find a voice and articulate their frustration with inadequate service, through surveying public opinion, organizing focus groups, using the mass media, forming partnerships with nongovernmental organizations, reconstruction of utility boards, and participation in regulatory hearings (Lovei & McKechnie, 2000).

In the fourth and fifth most impactful subcategories, Legal System (LS) and High Conflict Zones (HCZ), the input with the greatest impact is Kaolin, contributing to 35.8% and 28.3% of the characterized value of each subcategory, respectively. The first one, LS, evaluates the fragility of the country’s law system, and how impartial are the judiciary decisions. This subcategory is mainly based on the risk of fragility in legal system for each country sector, considering different indexes for this evaluation (such as CIRI Human Rights Index – Independent Judiciary or Global Integrity Index – Judicial Accountability/Rule of Law/Law Enforcement). The second one, HCZ, aims to assess the potential of a nation to have conflicts of interests both societal (civil, ethnic, and communal) and interstate warfare, and its data indicators are the number of conflicts and its intensity in each country sector, number of refugees, among others (SHDB, 2019). Around 39,4% of Kaolin was assumed to be produced in Portugal and the remaining 60,6% come from different countries around the world, being the largest share from UK (43.7%) (Growth Lab of Harvard University, 2018). This mineral is widely used in the pulp and paper industry both as a filler in the bulk of the paper and to coat its surface (IMA-Europe, 2021). Since this input has a significant contribution in both subcategories, it is important to identify which is the country that is contributing more to the social impacts of this mineral. Accordingly, Figure 13 represents the contribution share of each country where Kaolin is sourced from to the characterized value of both LS and HCZ subcategories.

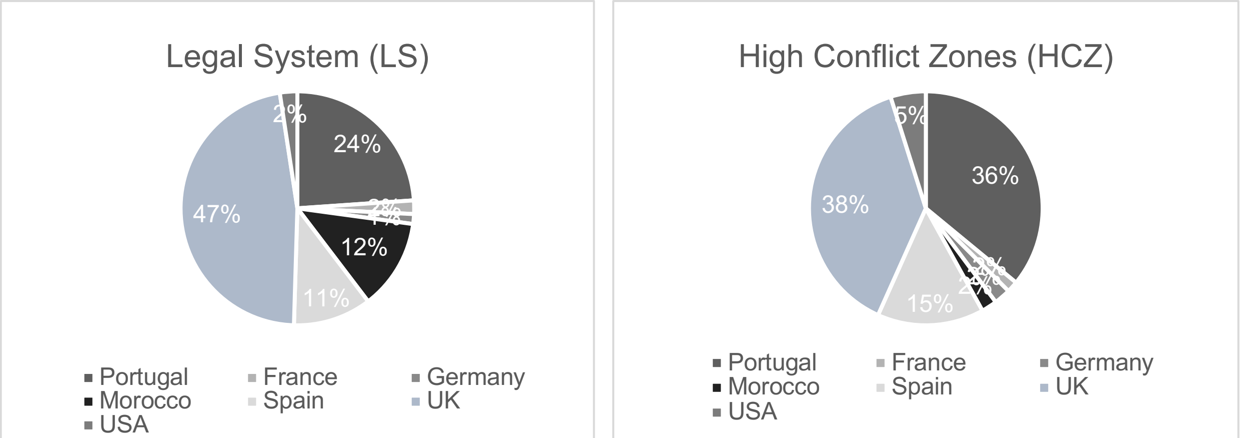


Figure 13: Contribution of each country to the characterized value of Kaolin in the Legal System (left) and High Conflict Zones (right) subcategories

From Figure 13, it is possible to observe that, in both subcategories analysed (LS and HCZ), the Kaolin imported from the UK has the highest contribution, representing 47% and 38% of the characterized value of Kaolin in each subcategory, respectively. In this sense, it is important to take actions concerning this input sourced from the UK and try to impose pressures on the suppliers to improve their legal system and to reduce the number of conflicts that occur in this country-specific sector. Notice that, in the HCZ subcategory, Kaolin produced in Portugal also has a significant impact, representing 36% of its characterized value (just two-point percent lower than UK). In this sense, actions concerning the Portuguese production of Kaolin and its social risks related to high conflict zones should be observed and improved.

Concluding, leaders operating in the pulp and paper industry should focus their attention on the Health & Safety of their workers, since this category has the highest contribution to the single score of this system. In addition, Product's Manufacture stage was identified as the most impactful in the five most critical subcategories analysed, and thus, this stage requires several improvements. Furthermore, Water is the input with the greatest concern in this stage, representing the highest contribution in the two most critical subcategories (IF and OTH). However, Energy and Kaolin (especially sourced from UK) inputs have a significant contribution in the other three subcategories and thus, these inputs should be monitored, in order to improve the social performance of the pulp and paper industry.

Recommendations to minimize the impact of the Water input should be based on applying the preventive measures proposed by ILO in the water treatment plants, considering both the injuries and fatalities that can occur in this industry and the risk of occupational toxic and hazards, due to the toxic substances used to disinfect water. In addition to these preventive measures, and since the paper industry requires huge quantities of water, companies should be innovative, applying the best available technology to improve their production efficiency and thus, minimize the use of resources (e.g., water, energy) and emissions to air or water (EPN, 2007). In this sense, waste heat recovery technologies and wastewater treatment solutions will be important to achieve this reduction (Boguniewicz-Zabłocka & Kłosok-Bazan, 2020). Moreover, increasing the share of production from recovered fibre could also considerably reduce energy use. To this end, expanding recycling channels can help increase the collection of paper for recycling (IEA, 2020). Finally, companies producing uncoated woodfree paper should reduce the brightness of products (which, in turn, reduces the levels of bleaching chemicals) and try to eliminate or find alternatives to the use of chlorine and chlorine compounds for bleaching, since these chemicals are dangerous for the environment and for the health of the company workers.

### 5.1.3.2. System 2 – Natural cork stoppers

Now, moving for System 2, it is firstly necessary to determine the most critical categories to the single score of this system. In this sense, Figure 14 represents the contribution share of the five categories considered in the SHDB to the single score value of System 2.

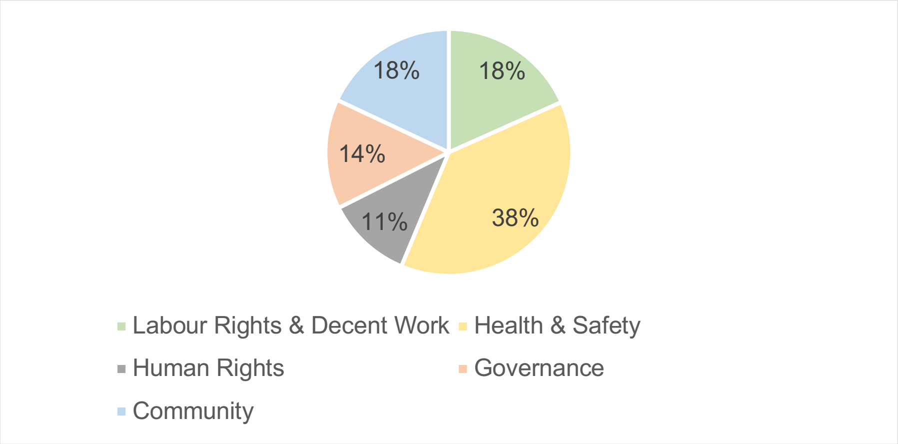


Figure 14: Contribution of each category to the single score of System 2

From the analysis of Figure 14, it is possible to conclude that the Health & Safety is the most critical category (38%), followed by both Labour Rights & Decent Work and the Community categories (18%), Governance (14%) and Human Rights (11%). As it was observed for the previous system, the Health & Safety category remains the most critical one. In fact, the worst working conditions are usually found in forestry. Forestry in general continue to be among the three most hazardous sectors even in European countries. Forestry workers are also beset by serious health problems, few reaching normal retirement age. Therefore, the first recommendation for the leaders in forest-based industries is to focus their attention on the Health & Safety category. In fact, efforts to improve occupational safety and health have increased in recent years and it is likely that this will be a continuing concern for the forest industry. However, while conditions in the manufacturing industry have improved considerably, the accident situation in forestry, especially in harvesting, give cause for concern (UNECE & FAO, 2003).

The previous five categories are now disaggregated into different impact subcategories. Figure 15 represents the Pareto analysis applied to the normalized values of each subcategory for System 2, in order to determine the most critical ones for this system.

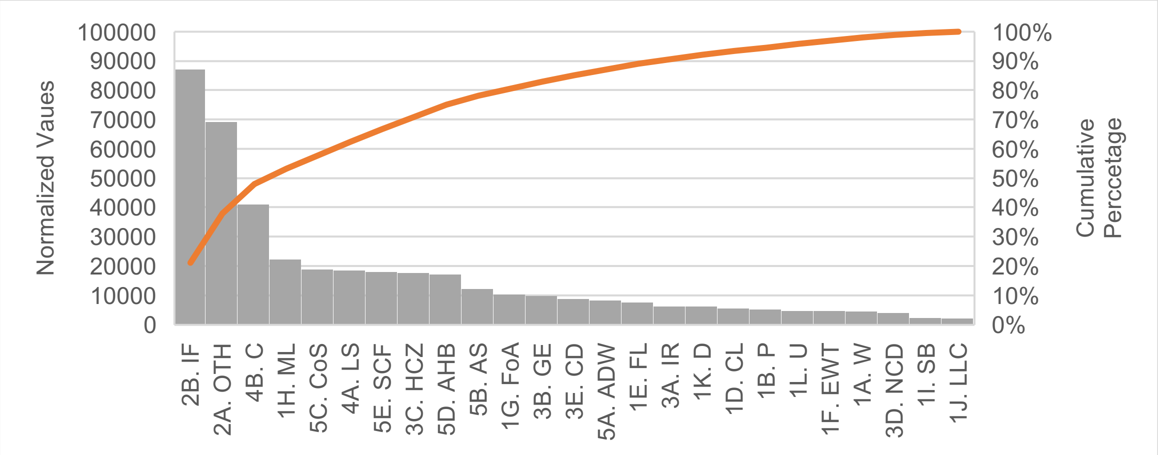


Figure 15: Pareto analysis considering the normalized values of the different subcategories in System 2

From Figure 15, it is possible to conclude that the most impactful subcategories, and the ones which contribute to approximately 80% of the total social impacts in System 2 are: Injuries & Fatalities (IF), Occupational Toxic & Hazards (OTH), Corruption (C), Migrant Labour (ML), Children Out of School (CoS), Legal System (LS), Smallholder vs. Commercial Farms (SCF), High Conflict Zones (HCZ) and finally, Access to Hospital Beds (AHB). As it was observed for System 1, the three most impactful subcategories remain the same, which are: IF, OTH and C. However, the fourth and fifth most critical subcategories have changed for this system, being: Migrant Labour (ML) and Children Out of School (CoS). The fourth one, ML, is related with the problems faced by migrant workers, which enjoy little social protection, face inequalities and discrimination in the labour market, and are vulnerable to exploitation and human trafficking. The fifth one, CoS, assesses the percentage of children in a specific country who are not attending the primary or secondary schooling. Ensuring that all children go to school and their education is of good quality are keys to preventing child labour (SHDB, 2019).

After determining the most critical subcategories for System 2, the next step in the results interpretation is to identify the life cycle stage which is contributing more to the social impacts of the five most impactful subcategories (IF, OTH, C, ML and CoS), in order to provide more precise and accurate recommendations for the companies operating in this industry. Accordingly, Figure 16 represents the contribution of each life cycle stage to the characterized values of the five most critical subcategories.

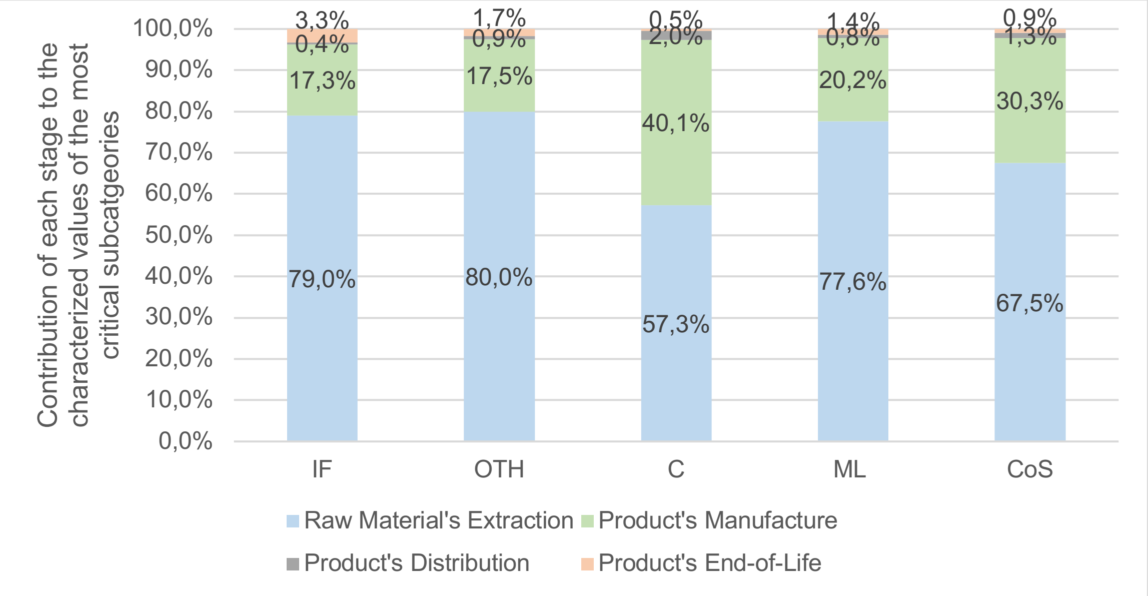


Figure 16: Contribution of each life cycle stage to the characterized values of the five most impactful subcategories for System 2

As it can be observed from Figure 16, the Raw Material's Extraction is the life cycle stage that contributes more to the social impacts of all these subcategories. Especially in the two most impactful subcategories, Injuries & Fatalities (IF) and Occupational Toxic & Hazards (OTH), this stage of the life cycle contributes to almost 80% of the total characterized value in both subcategories. Natural cork stoppers are, as the name indicates, a natural product manufactured using low amounts of chemicals and thus, it is understandable that the Product's Manufacture stage does not have a significant social impact on this system, as it was observed for the System 1, where the manufacture of UWF paper requires a variety of different chemicals and the consumption of a huge quantity of resources. On the other hand, the Raw

Material's Extraction is the stage which has the higher contribution on the social impacts of System 2 Therefore, this stage will be further analysed in detail.

The second most critical process in the life cycle of natural cork stoppers in all the five subcategories is the Product's Manufacture. Especially in the Corruption (C) subcategory, the third most impactful, the contribution of this stage is significantly higher than for the others, corresponding to 40,1% of the total social impacts of this subcategory (see Figure 16). In order to understand the main reasons behind this result, the Product's Manufacture stage in the Corruption subcategory will be studied, due to its significant contribution on this subcategory. Accordingly, Figure 17 represents the contribution of each input of the Product's Manufacture stage to the characterized value of the Corruption subcategory.

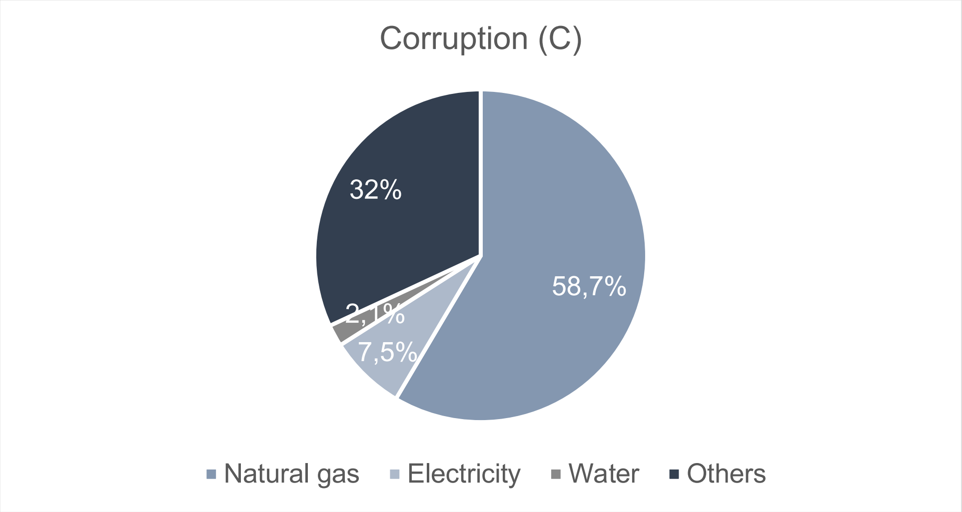


Figure 17: Contribution of each input to the characterized value of the Product's Manufacture stage in the Corruption subcategory

From Figure 17, it is possible to conclude that the Natural gas input has the greatest contribution to the social impacts of the Product's Manufacture stage in the Corruption subcategory, representing approximately 60% of its total characterized value. Portugal has no natural gas production and all the natural gas imported by this country comes from Spain (Growth Lab of Harvard University, 2018). Therefore, it is important to impose pressures on the Spanish suppliers of Natural gas. According to the Organisation for Economic Co-operation and Development (2016), the extractive industries (such as mining, oil, gas) are among the highest risk areas of business and one of the most prone sectors to corruption, accounting for one in five cases of transitional bribery (OECD, 2016). Natural resources have the potential to generate large revenues and profits, which make them attractive for business. At the same time, oil, natural gas, minerals and metals are critical energy sources for societies, being the predominant energy source for the world's population. As a result, extractive industries are usually under heavy government controls. However, these controls limit the public's insight into their resource management activities, such as controlling licenses, extraction contracts and safety regulations. Therefore, these points of contact between authorities and operators present high corruption risks (TI, 2021; U4, 2021). Hence, it is understandable that the natural gas input represents the highest share of contribution to the characterized value of the Product's Manufacture stage in the Corruption subcategory. Recommendations concerning both Natural gas and the Corruption problem should be based on: (1) reducing the amount of natural gas consumed in the production process; (2) imposing pressures and more restrict regulations on the natural gas production, especially from Spain; (3) substituting natural gas for another source of energy with less corruption practices; and (4) sourcing natural gas from another country with a better performance regarding the corruption social theme. A good indicator of Corruption is the Corruption Perceptions Index (CPI) published yearly by the Berlin-based Transparency International (TI), which ranks countries *"by their perceived levels of public sector corruption, according to experts and businesspeople"* (TI, 2020). For example, Norway is the 8th largest producer of natural gas in the world and, at the same time, occupies the 7th position in the CPI (TI, 2020; Statista, 2019). Therefore, sourcing natural gas from this country could be an interesting option. Although, social impacts regarding the transportation of natural gas from this country to Portugal may arise and thus, it needs to be studied to find out if it will be beneficial to import from this country.

Both the Product's Distribution and the Product's End-of-Life stages do not have a significant contribution to the social impacts of System 2, representing both less than 4% in all the five subcategories analysed (see Figure 16). Therefore, leaders in the cork industry should prioritize the other two stages (Raw Material's Extraction and Product's Manufacture).

Since the Raw Material's Extraction is the life cycle with the highest contribution, this stage will be analysed in detail, in order to determine the most critical input. Accordingly, Figure 18 represents the contribution share of each input to the characterized value of the Raw Material's Extraction in the five most critical subcategories.

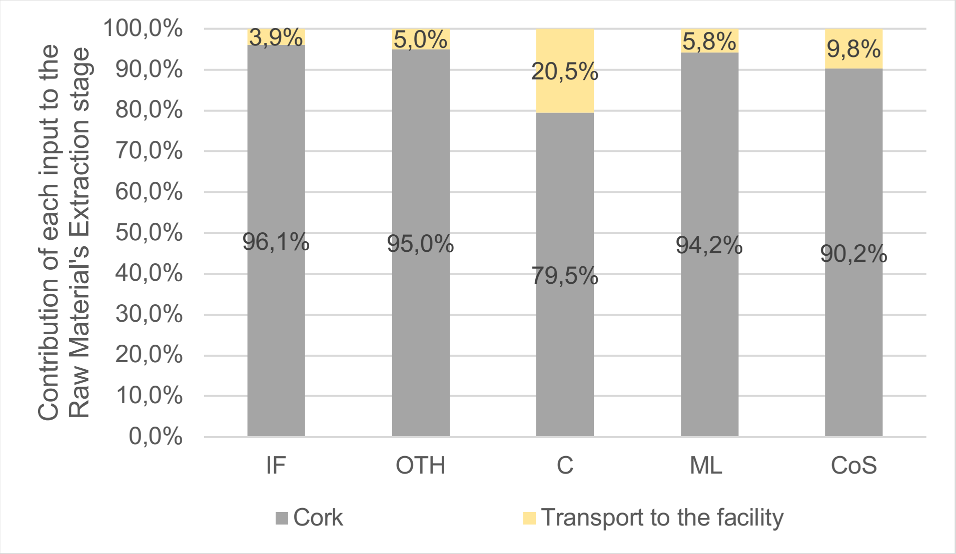


Figure 18: Contribution of each input of the Raw Material's Extraction to the characterized value of the five most critical subcategories

From Figure 18, it is possible to conclude that the raw material Cork is the most critical input to the Raw Material's Extraction stage in all the five subcategories analysed. Especially in the two most impactful subcategories, IF and OTH, this input has a huge impact, corresponding respectively, to 96.1% and 95.0% of the characterized values in each subcategory, which means that there is a high risk in the forestry sector of occurring injuries and fatalities (related to the IF subcategory) and, at the same time, a high risk of toxic noise levels, airborne particulates and occupational carcinogens (related to the OTH subcategory). In comparison, the transportation of Cork to the subregion *Área Metropolitana do Porto*, where the manufacture of natural cork stoppers was assumed to be only contribute 3.9% and 5.0% in the IF and OTH subcategories, respectively. In this sense, it is important to focus the attention on the cork extraction, in order to improve the social performance of this industry. As it was discussed in the Research Methodology chapter, the functional unit defined in this study is the exploration of 1 ha of forest land in Portugal for 100 years. Therefore, all the cork was assumed to have 100% Portuguese origin and thus, future improvements are dedicated to the Portuguese cork industry.

It is important to refer that the production of natural cork stoppers has a low process efficiency, requiring a huge quantity of raw material (cork) and, at the same time, generating high quantities of cork waste. To produce 1kg of natural cork stoppers, it is necessary 5kg of cork as raw material, which means that around 4kg of cork are wasted in this process (Santos et al., 2021). Although, many companies start using this cork waste for cork granulate to produce a variety of different products (from the automotive industry to civil construction products) (Amorim Cork Composites, 2021). Nevertheless, the manufacture of natural cork stoppers requires a significant portion of land to generate the raw material necessary and thus, it also requires a lot of work invested to extract this raw material. At the same time, the quantity of product (natural cork stoppers) obtained is not significant since there is a considerable waste in the production process. Furthermore, contrary to System 1 and 3, the extraction of raw material is done manually, and this may lead to different and generally higher social impacts than if it was done using machines. Du et al. (2019) conduct a SLCA considering a case study of sugarcane in Brazil, comparing the social impacts between manual and mechanical sugarcane harvesting. The results from this comparison are summarized in Table 18. Although the activity is not the same (sugarcane vs. cork harvesting), the social impacts do not vary significantly between both activities and thus, the main results of the study will serve as a support for the present research.

Table 18: Social impacts comparison of manual and mechanical harvesting by social theme (Adapted from Du et al., 2019)

| Social Theme | Manual Harvesting | Mechanical Harvesting |
|---|---|---|
| Health & Safety | 🟥 | 🟩 |
| Local employment | 🟩 | 🟥 |
| Fair salary | 🟥 | 🟩 |
| Access to material resources | 🟩 | 🟥 |
| Delocalization and migration | 🟥 | 🟩 |
| Public commitment of sustainability issues | 🟥 | 🟩 |
| Safety and Healthy living conditions | 🟥 | 🟩 |
| Equal opportunity and discrimination | 🟥 | 🟩 |

🟥 Worse performance

🟩 Better performance

Mechanical harvesting has lower impacts in most social themes, except for “Local employment” and “Access to material resources”, illustrating the widespread tension between labour intensity and machine use. According to the authors, the social theme with the highest concern for manual harvesting is Occupational Health & Safety. Exhaustion, back pain, occupational injuries due to fatigue, and high psychological stress are some examples of this concern, mainly due to the pressures to achieve high productivity. Furthermore, manual cutters are usually paid by productivity rather than a fixed wage and, as a result, this often motivates them to work beyond their physical limits (Du et al., 2019). In fact, results obtained from the SHDB confirms these statements, since the extraction of cork has the highest contribution in both IF and OTH subcategories, which belong to the category of Health & Safety. According to Souza et al. (2018), mechanical harvesting is expected to improve working conditions, average salary, and gender equity. However, at the same time, one mechanical harvester can replace 80 to 100 manual workers, which has negative impacts in terms of local employment. Nevertheless, the SHDB does not allow to distinguish between manual and mechanical harvesting, being one of this study’s limitations, which will be explored further in this section. Notwithstanding, it is important to verify the working conditions of manual cutters operating in the extraction of cork, since the occupational health & safety is a serious concern for manual harvesting (Du et al., 2019).

Notice that the contribution of the Transport to the facility input in the Corruption (C) subcategory is significantly higher than what is observed for the other four subcategories, representing 20.5% of the total characterized value of the Raw Material’s Extraction in this subcategory (see Figure 18), illustrating once again the correlation that exists between the transportation sector and the corruption social theme (Chen et al., 2020).

Concluding, since the Raw Material’s Extraction is performed manually and this process has the highest contribution to the overall social impacts of System 2, this provides good reasons for the companies operating in the cork industry to be aware of where their cork is being extracted and what are the working conditions on this stage, in order to improve their social performance. In this sense, extracting cork from socially responsible sources may lead to a significant reduction on the overall social impacts of the companies operating in this industry. Based on these results, the main actions for these companies are: (1) to promote better quality, formal employment and better working conditions, especially in the Raw Material’s Extraction stage; (2) to implement health and safety policies in all stages of forest work, from planning to implementation; (3) to reduce accidents and improve the overall accident rate; and lastly (4) to create training programs that target low-skilled jobs to improve both worker productivity and safety (ILO, 2019).

### 5.1.3.3. System 3 – Particle boards

Finally, moving for the last system, the first step of the results interpretation consists of identifying the most critical categories to the single score of System 3. In this sense, Figure 19 represents the contribution share of each category to the single score of this system.

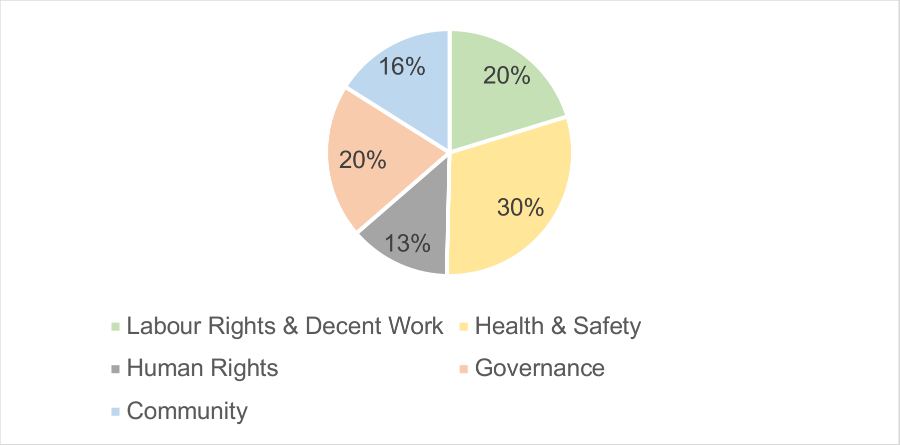


Figure 19: Contribution of each category to the single score of System 3

From Figure 19, it is possible to observe that the Health & Safety is the most critical category, representing 30% of the total single score of System 3, followed by both Labour Rights & Decent Work and Governance (20%), Community (16%) and Human Rights (13%). According to the Environmental, Health, and Safety (EHS) Guidelines, occupational health & safety hazards in particle boards manufacturing primarily include: (1) physical hazards; (2) exposure to noise; (3) dust inhalation; (4) chemical exposure; and (5) explosion/fire (EHS, 2007). In fact, the wood products industry has a poor image and often faces an uphill struggle in attracting new entrants due to the noise, dust, injuries, exposure to chemicals and high labour turnover, which are still features of many woodworking enterprises. However, the recent modernization of wood processing plants and the new technology has improved the safety and health conditions in this industry. Nevertheless, companies will have to review their safety and health regulations and consider the necessary revisions that are needed to cope with the swift changes in the forestry sector. In this context, it is important that both governments and the industry attach the highest priority to integrated safety and health programmes and to the involvement of management in such programmes (UNECE & FAO, 2003).

The previous five categories are now disaggregated into different subcategories of impact. In order to determine the most critical subcategories for this system, a Pareto analysis was conducted to the normalized values of each subcategory. The result of this analysis is represented in Figure 20.

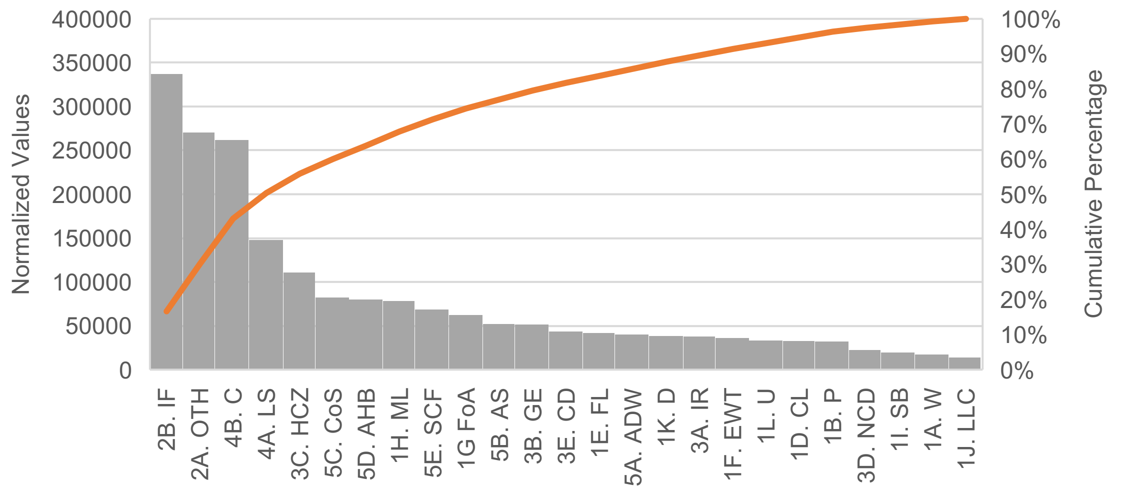


Figure 20: Pareto analysis considering the normalized values of the different subcategories in System 3

From Figure 20, it is possible to conclude that the most impactful subcategories, corresponding to approximately 80% of the total social impacts in System 2 are: Injuries & Fatalities (IF), Occupational Toxic & Hazards (OTH), Corruption (C), Legal System (LS), High Conflict Zones (HCZ), Children Out of School (CoS), Assess to Hospital Beds (AHB), Migrant Labour (ML), Smallholder vs. Commercial Farms (SCF) and finally, Freedom of Association (FoA). As it was observed for the other two systems, the most impactful subcategories (IF and OTH) belong to the category of Health & Safety. Therefore, one can conclude that this category is a social area of concern for the forest sector in general.

The same approach as for the other two systems is applied and the five most impactful subcategories (IF, OTH, C, LS and HCZ) corresponding to 20% of the total number of subcategories included in the method, are now analysed in detail to determine the most critical life cycle stage and the one which requires more attention. Accordingly, Figure 21 represents the contribution of each stage to the five most impactful subcategories in this system.

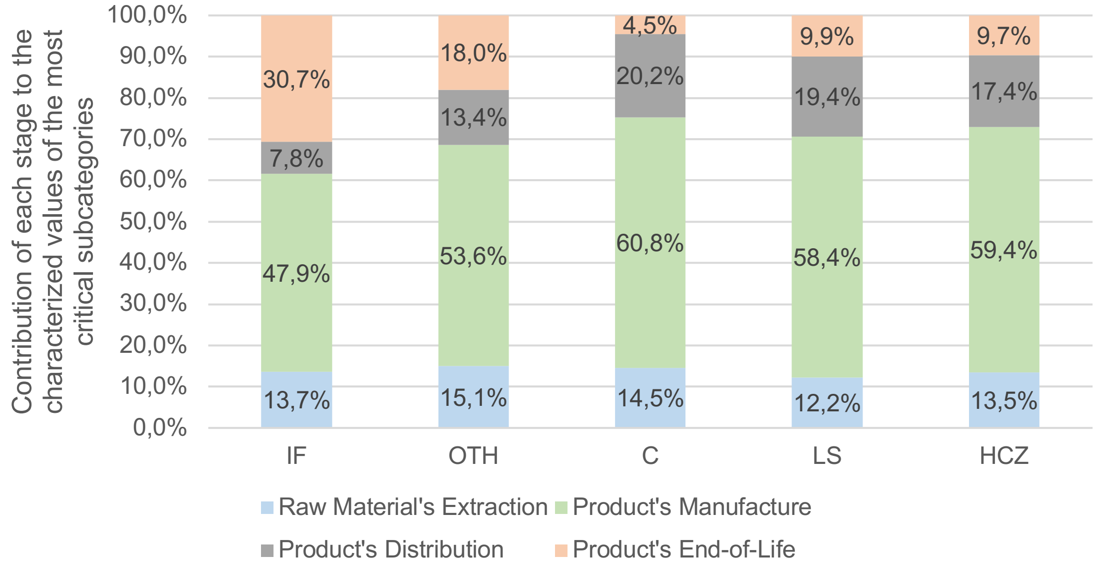


Figure 21: Contribution of each life cycle stage to the characterized values of the five most impactful subcategories for System 3

As it can be observed from Figure 21, the life cycle stage with the highest contribution in all the subcategories analysed is the Product's Manufacture stage. Especially in the Corruption (C) subcategory, this stage contributes to around 61% of the total characterized value of this subcategory. Therefore, companies producing particle boards should focus their attention on this life cycle stage and try to understand the main reasons for its higher social impact.

The second most critical life cycle stage in the two most impactful subcategories, IF and OTH, is the Product's End-of-Life, representing respectively 30.7% and 18.0% of the total characterized value of each subcategory. Therefore, one can conclude that the recycling, incineration, and combustion of particle boards has a higher risk of occurring injuries and fatalities, risk of toxic noise levels and risk of occupational carcinogens and airborne particles. Regarding the other three subcategories (C, LS, HCZ), the Product's Distribution is the second most impactful stage, contributing to around 20% of the total characterized value. In this sense, both stages (Product's End-of-Life and Product's Distribution) also require improvements and should be monitored by all the companies operating in the wood industry.

Since the Product's Manufacture is the most impactful life cycle stage in System 2, it is important to determine what are the input materials that are contributing more to the social impacts of this process in the five most critical subcategories, in order to provide more specific recommendations for the companies to reduce the negative social effects of this stage. In this sense, Figure 22 represents the contribution of each input to the characterized value of the Product's Manufacture stage in each critical subcategory.

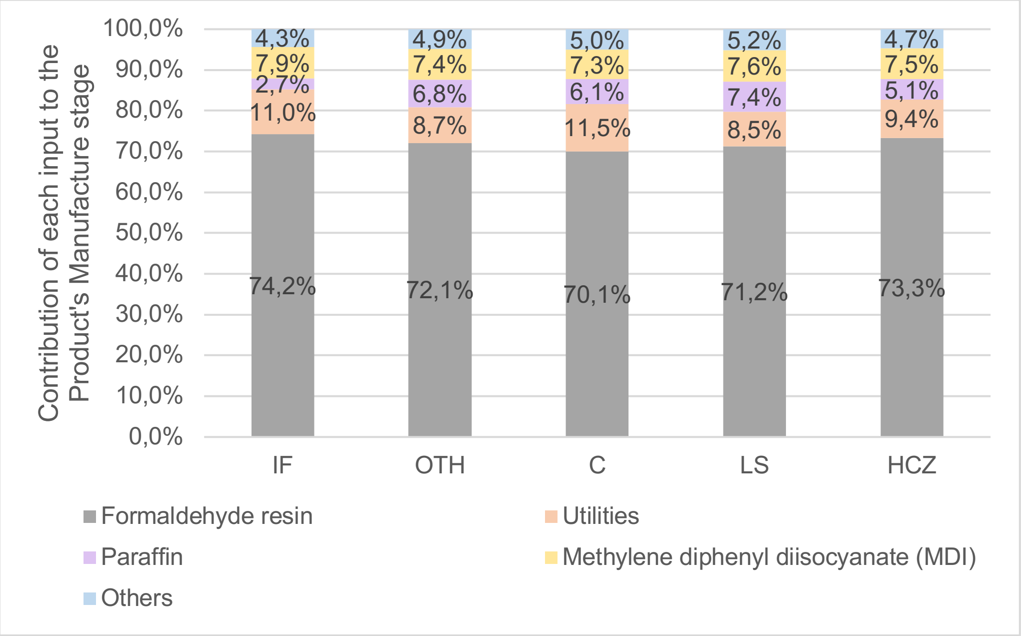


Figure 22: Contribution of the main inputs in the Product's Manufacture stage to the characterized value of the most critical subcategories

From Figure 22, it is possible to conclude that the Formaldehyde resin input has a huge impact on the Product's Manufacture stage, contributing to more than 70% of the total characterized value in all the five subcategories analysed. Formaldehyde resin is a colorless, flammable and strong-smelling chemical that is used in the production of glues for the manufacturing of pressed wood products, including plywood, fibreboards and particle boards. In addition, this chemical is commonly known as a preservative in medical laboratories and mortuaries, and it is also used as an industrial fungicide, germicide and disinfectant. It was considered in this study that around 39.4% of Formaldehyde is produced in Portugal and the remaining 60.6% is imported from four different European countries, which are: Germany, Italy, Spain and Sweden (Growth Lab of Harvard University, 2018). Due to the relevant contribution of this chemical to the Product's Manufacture stage, it is important to identify the countries that are contributing more to the negative social impacts of this input. In this sense, Figure 23 represents the contribution share of each country where Formaldehyde resin is sourced from to the characterized value of this chemical in the five most critical subcategories.

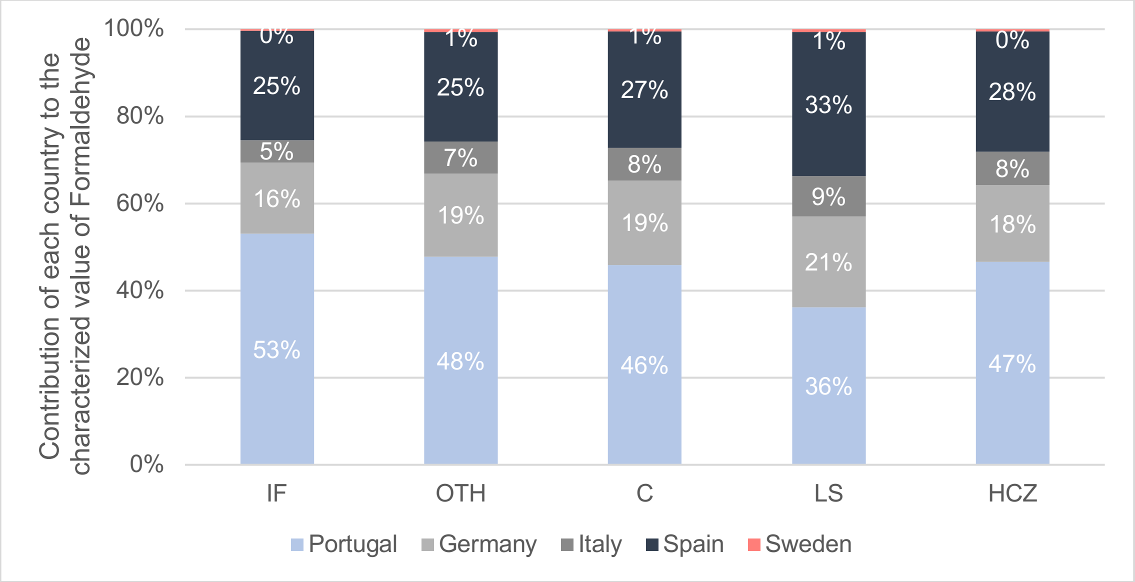


Figure 23: Contribution of each country to the characterized value of Formaldehyde resin in the five most critical subcategories

From Figure 23, it is possible to observe that Formaldehyde resin produced in Portugal represents the highest contribution, followed by Spain, Germany, Italy and finally, Sweden. Except for the Legal System (LS) subcategory, Formaldehyde resin from Portugal represents almost half of the total characterized value of this input in all the subcategories analysed. In this sense, it is important to be aware of where companies manufacturing pressed wood products are sourcing this chemical, especially from Portugal.

Notice that, when formaldehyde is present in the air, individuals may experience adverse effects such as burning sensations in the eyes, nose and throat; coughing; wheezing; nausea and skin irritation (NIH, 2021). In addition, formaldehyde is also a suspected human carcinogen that is linked to nasal cancer and lung cancer. Due to the negative effects on the workers' health, the Occupational Safety and Health Administration established the Permissible Exposure Limits (PELs) for formaldehyde at the workplace, which is 0.75 parts formaldehyde per million parts of air (0.75 ppm) measured as an 8-hour time weighted average (OSHA, 2002). In this sense, this imposed limit by authorities can restrict the number of particle boards produced by a company, as well as the number of particle boards bonded with these resins used indoors (Irle, 2010). As a result, companies from the wood industry should find alternatives for formaldehyde-based resins in the production of pressed wood products, since this chemical is a hazard for the society in general, which can be confirmed by the significant social impacts obtained through the software. While there is no alternative, it is important to train all employees exposed to formaldehyde to know how to handle with this chemical and to provide them the appropriate personal protective equipment (such as clothing, glove, aprons) to prevent skin and eye contact with formaldehyde (OSHA, 2002).

Concluding, companies operating in the pulp and paper industry should focus their attention on the Product's Manufacture stage, since this process is the most critical in all the subcategories analysed. Furthermore, the Formaldehyde resin that is used in the manufacturing process has a huge social impact in the five most critical subcategories, being Portugal the country with the highest contribution on the social impacts of this input. As a result, companies from the wood industry producing this type of products might consider other non-formaldehyde resins. Besides its environmental impacts, this resin contains a variety of toxic compounds that threatens the health of workers in this industry. Moreover, the limit imposed by authorities reinforces the importance on considering an alternative for this resin in the manufacturing process.

It should be noted that the results observed in this section for the three systems under study must be interpreted with care due to the limitations of this study. These limitations are mostly due to the choice of the SHDB as a data source. In the SHDB, data on sector level are rather roughly divided and for some sectors or countries there is no available data (e.g., Algeria). The GTAP sector used for chemicals (which is chemicals, rubber and plastic), appears from its name to include quite a variety of different subsectors, and might therefore not be a true and fair representative for the sector in question (Ekener-Petersen et al., 2014). The same happens for the different raw materials required in the three systems (pulpwood, cork and roundwood), which are all included in the same GTAP sector (forestry). In addition, the database has limited ability to distinguish between different production routes, such as manual and mechanical harvesting, and it is known that this significantly affects the social impacts (Du et al., 2019). Furthermore, data in the SHDB are based on countries since the statistics used are often collected on a country basis. However, there may be differences between, for example, different producers within a sector in a specific country. These potential differences are concealed when data on a national level are used (Ekener-Petersen et al., 2014). Finally, the social categories and social themes selected in the SHDB are generic and not specifically adapted to the forest-based industries under study. Concluding, SHDB is a useful tool to identify social risks associated with a country-specific sector, as well as to identify social hotspots in the life cycle of products and services. However, this database needs to incorporate more detailed data, in order to provide more robust and differentiating results. According to Ekener-Petersen et al. (2014), the higher level of detail could be achieved by disaggregating GTAP sectors to be more representative for the sector in question, by dividing countries into different regions (especially for the large ones such as China, Brazil, USA) and lastly, by including more data from more countries and sectors to reach more supply chain configurations.

Another important source of limitations is due to some of the assumptions made in the LCI step of the SLCA methodology. Firstly, it was not included the price at each specific country since it would be a very difficult task and a time-consuming process to collect data on a country level for all the required materials. In addition, the price of each input has some uncertainty associated since it depends on several different factors (e.g., quantity purchased, type of delivery, transport distance of delivery). Therefore, the estimation of risk hours in the SHDB, which is based on approximated work hours via the added value of the processes (monetary value) of each country might be influenced by fluctuations in the price levels between countries. Secondly, it was assumed in this study that the chemicals' domestic production was the same for all the inputs (39,4%), which in fact, it is not true and may affect the results. Additionally, only countries that contribute more than 1% to the exports of the three products and imports of the input materials required to model the systems were considered. Furthermore, even though wood and cork have different compositions, the end-of-life destinations of the natural cork stoppers were considered to be similar to the particle boards, as it was applied in Santos et al. (2021).

Concluding, the results from this work can serve as a preliminary assessment of the social sustainability of the three major Portuguese forest-based industries and its respective most manufactured products. Since this topic is still not yet assessed and the SLCA methodology is still under development, every study regarding the social dimension of the forest sector is important to obtain conclusions and to provide recommendations for all the stakeholders involved (e.g., forest companies, organisations, government). However, the results obtained in this work should be interpreted with care and subjectivity, due to the limitations identified previously. In order to provide more accurate results, some aspects regarding the SHDB should be improved and data regarding the different prices and domestic production of the inputs required to model the systems should be more accessible. Due to the uncertainty associated with the different price levels, the next subsection will conduct a sensitivity analysis to the prices of the most critical inputs for each system, in order to understand their influence on the final results.

### 5.1.3.4. Sensitivity Analysis

As it was discussed previously, one of the main limitations of this study is related with the prices collected for the different inputs required to model the three systems. These prices have uncertainty associated and, for this reason, a sensitivity analysis was conducted. This type of analysis allows to understand how the results of this study are affected by the uncertainty of the input data used (Santos et al., 2019). The following sensitivity analysis focus on understanding the influence of a price variation for the inputs with the highest contribution in the most critical stage for each system. Accordingly, the prices of the two most critical inputs were changed, and their respective contributions to the critical stage for each of these variations were registered. The results of this analysis are presented from Figure 24 to 27. Each Figure contains two lines, one for each input material. The most critical input suffers small reductions in the price and, simultaneously, the second most critical input suffers small increases in the price (x-axis). The main goal of this analysis is to understand if it is necessary a large reduction and, simultaneously, a large increase in the price originally used, for the second most critical input to become the most critical one i.e., the contribution of the second critical input becomes higher than the contribution of the most critical one considering different variations (y-axis).

#### System 1

For this System, Water and Kaolin were identified as the most critical inputs in the most impactful subcategory (IF), considering the Product's Manufacture stage. To determine the impact of a variation in the prices collected for both inputs, a sensitivity analysis was conducted, being represented in Figure 24. The x-axis represents the percentage of reduction and increase in the price of Water and Kaolin, respectively. For each price variation, the contribution of each input to the Product's Manufacture stage in the IF subcategory was registered and it is represented in the y-axis of Figure 24.

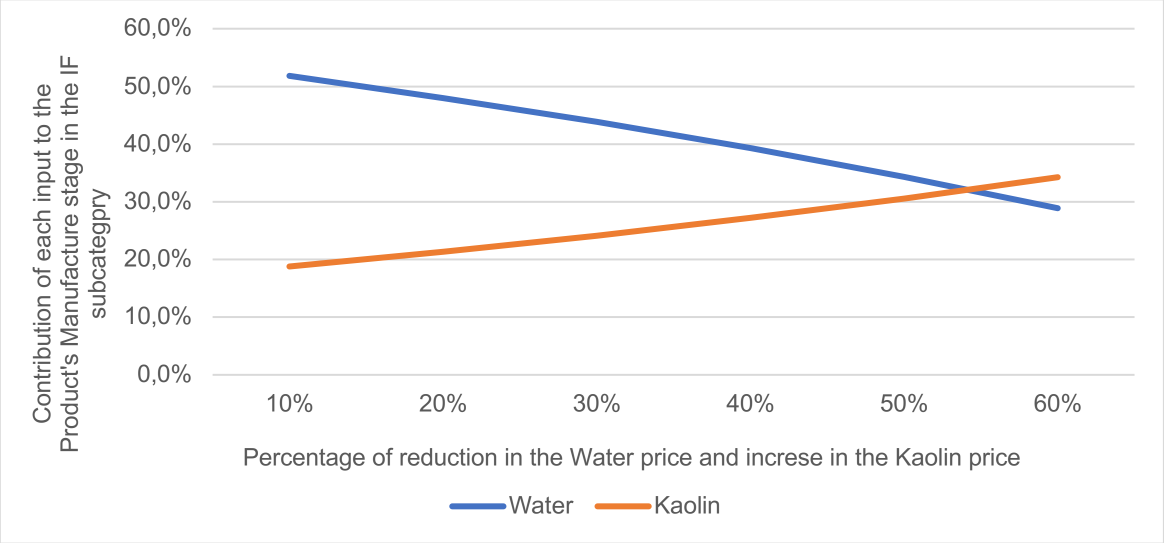


Figure 24: Sensitivity analysis considering the price variations of the most critical inputs in the IF subcategory

From the analysis of Figure 24, it is possible to observe that it is necessary a reduction of more than 50% in the Water price and, simultaneously, an increase of more than 50% in the Kaolin price originally considered for this last input (Kaolin) to become the most critical one in the Product's Manufacture stage for the IF subcategory. Therefore, the conclusion that Water is the most critical input in the IF subcategory is consider reliable, since only a large reduction and increase in the Water and Kaolin prices, respectively, will lead to a change in the final conclusions obtained. In this sense, companies in the pulp and paper industry should focus their efforts on reducing the Water contribution, especially considering both the high risk of injuries and fatalities and occupational toxic and hazards that exists the water treatment installations.

In addition to the sensitivity analysis conducted in the IF subcategory, the same analysis was performed in the HCZ subcategory, but now considering Kaolin and Potato Starch, since both inputs are the most critical ones in this subcategory. Contrary to the IF subcategory, where the Water input has a significant contribution to the social impacts of the Product's Manufacture stage, the different inputs' contributions are well distributed in the HCZ subcategory. Furthermore, the difference between the contribution of Kaolin and Potato Starch is low (28.3% of Kaolin vs. 22.1% of Potato starch). Therefore, the sensitivity analysis was performed to understand the impact of a variation in the price of these inputs to the conclusions obtained. Figure 25 represents the sensitivity analysis conducted for the HCZ subcategory.

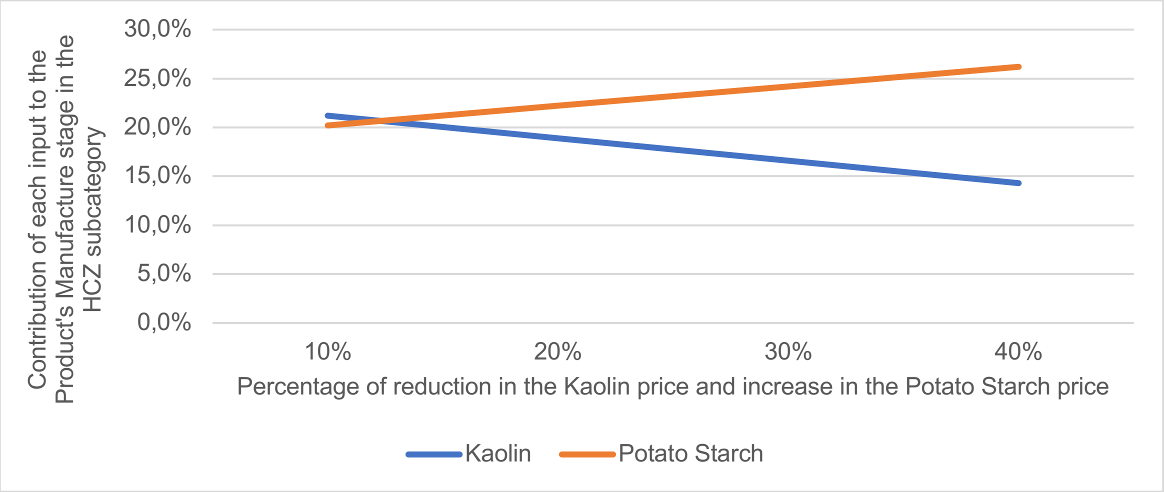


Figure 25: Sensitivity analysis considering the price variations of the most critical inputs in the HCZ subcategory

From the analysis of Figure 25, it is possible to conclude that a small reduction in the price of Kaolin and, simultaneously, a small increase in the price of Potato starch is needed for this second input (Potato starch) to become the most critical one in the HCZ subcategory. In this sense, one can conclude that the robustness on saying that Kaolin is the most critical input in the HCZ subcategory is low and thus, both inputs in this subcategory require attention and should be analysed in detail, considering the risk of occurring conflicts in this specific industry.

## System 2

In this System, the Cork was identified as the most critical input in the Raw Material's Extraction stage in the five subcategories analysed. This stage in System 2 only contains two parameters: Cork and the Transport to the facility since the cork extraction is performed manually. In this sense, a sensitivity analysis was conducted to both inputs, in order to understand if a change in their prices would affect the final conclusions obtained. This analysis will focus on the Corruption (C) subcategory, since it is in this subcategory where the Cork contribution is lower, corresponding to 79.5% of its social impacts.

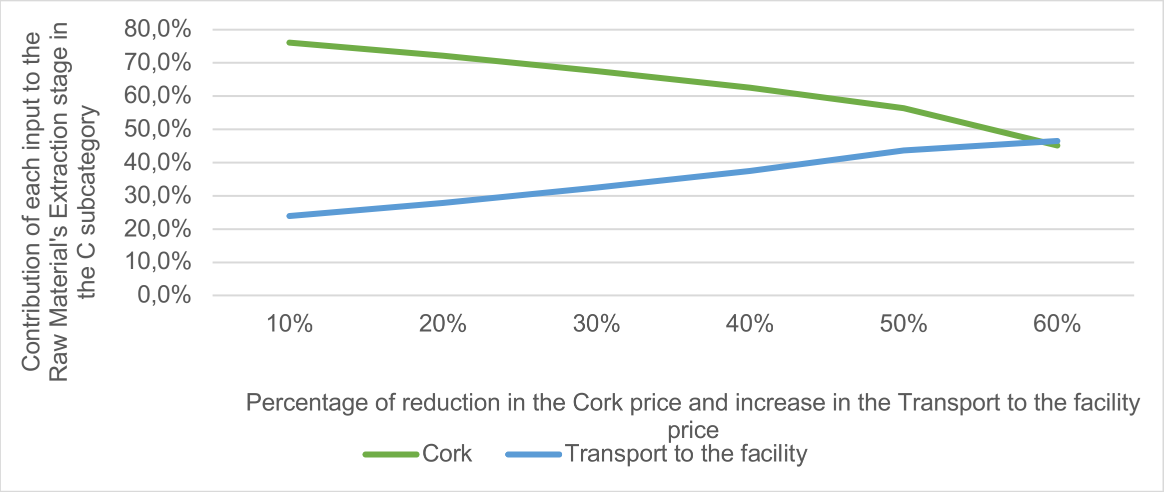


Figure 26: Sensitivity analysis considering the price variations of the most critical inputs in the C subcategory

From Figure 26, it is possible to observe that it is necessary a reduction of 60% in the price of Cork and, simultaneously, an increase of 60% in the price of the Transport to the facility to occur an intersection of both lines in Figure 26 (i.e., when the contribution of cork equals the contribution of the transport to the facility in the Corruption subcategory). In this sense, if different cork and transport prices had been considered, the results achieved in terms of what is the most critical input in the Raw Material's Extraction stage for the five subcategories would not change, since only large reductions or increases in the price of each input would lead to different conclusions. Therefore, the conclusion that Cork is the most critical input for System 2 is consider reliable and thus, the Portuguese cork requires significant improvements in the five most critical subcategories, in order to reduce the social impacts of the companies operating in this industry.

**System 3**

Finally, in this system, the Formaldehyde resin was identified as the most critical input in the Product's Manufacture stage for the five subcategories analysed, contributing to more than 70% of the characterized value of each subcategory. In addition, the Utilities (such as electricity, water) is the second most critical input in the same five subcategories. In this sense, the prices of both inputs were changed (x-axis) and the respective contribution to the Corruption subcategory was registered (y-axis), since it is in this subcategory that the Formaldehyde resin has the least contribution. Accordingly, Figure 27 represents the contribution of each input considering the different price variations. The most critical input (Formaldehyde resin) suffers successively reductions of 10% in the price and, simultaneously, the Utilities suffers small increases of 10% in its price.

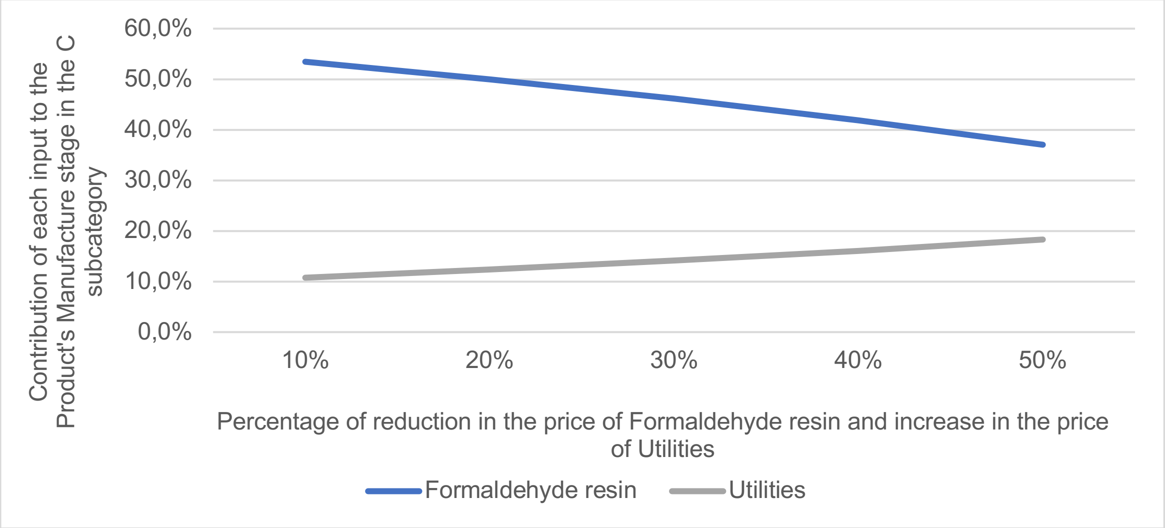


Figure 27: Sensitivity analysis considering the price variations of the most critical inputs in the C subcategory

From the analysis of Figure 27, it is possible to conclude that, even if the prices of both Formaldehyde and Utilities inputs change, the Formaldehyde resin will continue to be the most critical input in the Product's Manufacture stage. For example, if a reduction of 50% in the price of Formaldehyde resin was considered and, simultaneously, an increase of 50% in the price of Utilities, the Formaldehyde resin will continue to be the most critical input for System 3, having a contribution of approximately 37.1% of the

Product's Manufacture stage for the Corruption subcategory. Therefore, the conclusion that Formaldehyde resin is the most critical input is considered reliable and thus, this chemical requires improvements considering the five most critical subcategories.

## 5.2. Step 2 – Comparison of systems

This second step aims to compare the three systems by analysing the results obtained through the SLCA application in the previous step. The first comparison between the three systems is performed at the midpoint level, by comparing the characterized values of each subcategory of impact. In this sense, Table 19 represents the characterized values for each system and subcategory in three different forms: (1) values considering the functional unit defined (Total); (2) values per kg of product manufactured; and (3) values per Net Present Value (NPV) generated by selling the previous quantity of products. The values of NPV were retrieved from the article proposed by Santos et al., (2021), which are: 34213.09 euros for System 2, 353.13 euros for System 2, and for 6093.7 euros System 3.

Table 19: Characterized values of the different subcategories considered in the three systems (total, per kg of product manufactured and per NPV generated)

| Impact Subcategory (Mrheq) | System 1 | | | System 2 | | | System 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Per kg | Per NPV | Total | Per kg | Per NPV | Total | Per kg | Per NPV |
| **1A Wage** | 78642 | 0,15 | 2,30 | 2502 | 0,85 | 7,09 | 9898 | 0,07 | 1,62 |
| **1B Poverty** | 147623 | 0,28 | 4,31 | 2846 | 0,97 | 8,06 | 17562 | 0,12 | 2,88 |
| **1D Child Labour** | 137854 | 0,26 | 4,03 | 3021 | 1,03 | 8,56 | 18102 | 0,12 | 2,97 |
| **1E Forced Labour** | 207994 | 0,39 | 6,08 | 4178 | 1,43 | 11,83 | 23212 | 0,15 | 3,81 |
| **1F Excessive Working Time** | 200518 | 0,38 | 5,86 | 2555 | 0,87 | 7,23 | 19979 | 0,13 | 3,28 |
| **1G Freedom of Association** | 307723 | 0,58 | 8,99 | 5723 | 1,95 | 16,21 | 34469 | 0,23 | 5,66 |
| **1H Migrant Labour** | 405766 | 0,77 | 11,86 | 12200 | 4,16 | 34,55 | 43438 | 0,29 | 7,13 |
| **1I Social Benefits** | 108600 | 0,20 | 3,17 | 1248 | 0,43 | 3,53 | 10923 | 0,07 | 1,79 |
| **1J Labour Laws/Conventions** | 70546 | 0,13 | 2,06 | 1117 | 0,38 | 3,16 | 7747 | 0,05 | 1,27 |
| **1K Discrimination** | 179435 | 0,34 | 5,24 | 3453 | 1,18 | 9,78 | 21477 | 0,14 | 3,52 |
| **1L Unemployment** | 126496 | 0,24 | 3,70 | 2617 | 0,89 | 7,41 | 18478 | 0,12 | 3,03 |
| **2A Occupational Toxic & Hazards** | 241077 | 0,46 | 7,05 | 6912 | 2,36 | 19,57 | 27044 | 0,18 | 4,44 |
| **2B Injuries & Fatalities** | 349126 | 0,66 | 10,20 | 8707 | 2,97 | 24,66 | 33717 | 0,22 | 5,53 |
| **3A Indigenous Rights** | 84605 | 0,16 | 2,47 | 1576 | 0,54 | 4,46 | 9606 | 0,06 | 1,58 |
| **3B Gender Equity** | 119973 | 0,23 | 3,51 | 2427 | 0,83 | 6,87 | 12977 | 0,09 | 2,13 |
| **3C High Conflict Zones** | 222846 | 0,42 | 6,51 | 4408 | 1,50 | 12,48 | 27757 | 0,18 | 4,56 |
| **3D Non-Communicable Diseases** | 49624 | 0,09 | 1,45 | 988 | 0,34 | 2,80 | 5696 | 0,04 | 0,93 |
| **3E Communicable Diseases** | 88742 | 0,17 | 2,59 | 2197 | 0,75 | 6,22 | 10965 | 0,07 | 1,80 |
| **4A Legal System** | 129146 | 0,24 | 3,77 | 1837 | 0,63 | 5,20 | 14795 | 0,10 | 2,43 |
| **4B Corruption** | 222167 | 0,42 | 6,49 | 4092 | 1,40 | 11,59 | 26224 | 0,17 | 4,30 |
| **5A Access to Drinking Water** | 73271 | 0,14 | 2,14 | 2037 | 0,70 | 5,77 | 10078 | 0,07 | 1,65 |
| **5B Access to Sanitation** | 106913 | 0,20 | 3,12 | 3033 | 1,04 | 8,59 | 13190 | 0,09 | 2,16 |
| **5C Children out of School** | 174776 | 0,33 | 5,11 | 4702 | 1,60 | 13,31 | 20558 | 0,14 | 3,37 |
| **5D Access to Hospital Beds** | 193633 | 0,37 | 5,66 | 4271 | 1,46 | 12,09 | 20027 | 0,13 | 3,29 |
| **5E Smallholder vs Commercial Farms** | 146722 | 0,28 | 4,29 | 4484 | 1,53 | 12,70 | 17202 | 0,11 | 2,82 |

Regarding the values considering the functional unit defined in this study (column "Total"), it is possible to observe from Table 19 that System 2 has the least characterized values and System 1 has the greatest characterized values in all the subcategories analysed. Moreover, the values of System 1 are significantly higher, due to the difference between the amount of product obtained from the exploration of 1 hectare of forest land for 100 years (functional unit selected), which results in, for example, 2929.86 kg of natural cork stoppers vs. 529840.41 kg of uncoated woodfree paper. Therefore, one can conclude that the results obtained through the SHDB are related with the quantity of product considered in each system. In this sense, the characterized values were divided by the respective quantity assessed, as well as the NPV generated, and the conclusions are different: System 2 has the greatest characterized values considering both indicators (per kg and per NPV) in all the subcategories analysed. Hence, this system has the worst performance when considering both a social and economic perspective. On the other hand, System 3 has the lowest characterized values per kg of product manufactured and per NPV generated, being the system with the best performance.

It is important to refer that, when the Pareto analysis was applied to the normalized values of the impact subcategories included in Table 19, the three systems under study share the same three most critical subcategories, which are: IF, followed by OTH and C. Therefore, one can conclude that most social issues in the forest sector arise from these subcategories. Regarding the comparison at the endpoint level, it was observed that all the three systems share the same two most critical categories, which are: Health & Safety and Labour Rights & Decent Work.

Finally, the single score values of each System are compared, reinforcing the conclusions obtained previously through the characterized values of Table 19. The Single Score values (expressed in kPt) for the three systems under study are represented in Figure 28.

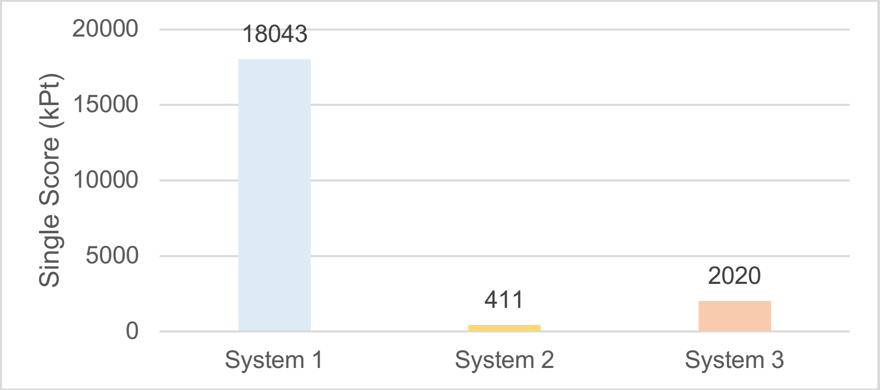


Figure 28: Single score comparison between the three systems

From the analysis of Figure 28, it is possible to conclude that System 2 has the best social performance and System 1 has the worst social performance, considering the functional unit defined, which is the exploration of 1 ha of forest land in Portugal for 100 years. Therefore, if the goal was to choose the best forest specie from a social point of view that can be planted in 1 ha of forest land between *Eucalyptus globulus* to produce uncoated woodfree paper, *Quercus suber* to produce natural cork stoppers, and *Pinus pinaster* to produce particle boards, planting *Quercus suber* will be the best option since this system has the lowest Social single score for the same system boundary and functional unit considered. Notice that the differences between the single score of System 1 and both System 2 and 3 are very contrasting since the quantities used to model these systems in the software are also very different. In this sense, the single score values obtained for the three systems were divided by the quantity of final product obtained (left column) and divided by the NPV generated by selling the previous quantity (right column), as it was done for the characterized values in Table 19. Accordingly, Figure 29 represents the social impact (expressed in kPt/kg and kPt/euro) comparison between the three systems under study.

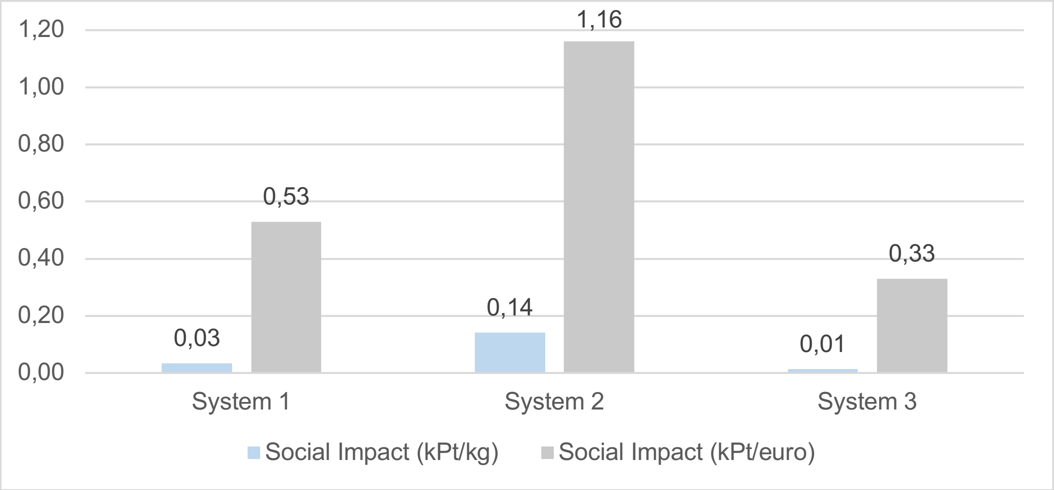


Figure 29: Social impact comparison per kg of product manufactured (left column) and per NPV generated (right column) between the three systems

Regarding the single score values per kg of product manufactured, the same conclusion cannot be observed. In this case, System 3 has the best social performance per kg of product generated, which means that if a company has to choose between the production of a specific amount (measured in kg for example) of uncoated woodfree paper, natural cork stoppers or particle boards, regardless the dimensions of land that can be used, the production of particle boards (System 3) would be the best option from a social point of view, since this system has the lowest single score per kg of product manufactured. At the same time, this system has the least social impact per NPV calculated and thus, this system has the best performance considering both a social and economic perspective. Therefore, planting *Pinus Pinaster* to produce particle boards will have the best social performance and will generate the greatest NPV.

After studying the social impacts of the three forest-based industries, some similarities between them can be discussed, which means that, regardless of the forest industry considered, a common concern is observed and thus, conclusions about social sustainability of the forest sector can be provided:

- The same three impact subcategories (IF, OTH and C) are the most critical in the three systems analysed, leading to a common concern across the forest sector. Hence, when assessing and reporting the social impacts of the forest sector, governmental organizations and other stakeholders should focus their attention on these three impact subcategories. Moreover, companies operating in the forest sector should try to reduce its negative effects by implementing safety policies in the workplace, as well as using both socially and environmentally sustainable sources of inputs. Despite being different sustainability dimensions, the environmental and social pillars are correlated since the pollution of the environment affects the health of the society.

- The category with the highest contribution to the single score in the three systems is the Health & Safety category, followed by the Labour Rights & Decent Work. According to the Occupational Health & Safety Administration, the forest industry is considered as a high-risk work, with the sector having high fatal and major injuries rates (OSHA, 2021). In this sense, companies in the forest sector should focus their attention on the following aspects: (1) ensure that workers receive the necessary information on safety and health risks and preventive measures; (2) ensure that each worker receives adequate and job-specific safety training; (3) ensure that an overall assessment of the risks is made; and (4) consult workers and encourage them to participate in meetings to discuss where improvements should be done.
- Regarding the life cycle stage which contributes more to the overall single score, the Product's Manufacture stage has the highest contribution in both System 1 and System 3, since large quantities of resources (e.g., water and energy) are consumed in this stage and different dangerous chemicals are used (e.g., formaldehyde, chlorine), which threatens the health of the workers and at, the same time, may result in different injuries and accidents at the workplace. Therefore, companies should find alternatives to the hazardous chemicals and try to be more efficient in their production operations. On the other hand, the Raw Material's Extraction is the most critical life cycle stage in System 2, being cork the input with the highest contribution on this stage. The production of natural cork stoppers requires a large amount of cork, resulting in few quantities of final product and a lot of work invested to extract this raw material.
- An interesting result observed during the results' interpretation was the contribution of the Transport input in the Products' Distribution (for both System 1 and 3) and the Transport to the facility (for System 2) in the Corruption (C) subcategory, which is higher than for the other ones. In this sense, one can conclude that the transportation sector in one of the more prone corruption sectors (Chen et al., 2020), and this concern should be analysed by the all the companies, when considering the distribution of their products. In addition, it was observed that the inputs with the greatest impact in this subcategory are Energy (in System 1) and Natural Gas (System 2), illustrating the high correlation that exists between corruption and the extractive industries (oil, mining, gas), which can be confirmed by the literature (Kasekende et al., 2016).

The present work also allows to discuss some specific recommendations for the three industries under study (pulp and paper, cork and wood industries). These recommendations will be based on reducing the social impact of the most critical input in the most impactful life cycle stage for each system:

- In the pulp and paper industry, the use of Water is the most critical input in the Product's Manufacture stage, since it has the higher contribution in the two most impactful subcategories (IF and OTH). All the water used to model this system is from Portugal and thus, attention should be assigned to the Portuguese water treatment installations. In order to minimize its social effects, it is necessary to implement different preventive measures recommended by the ILO at the workplace, such as use appropriative ear protection and clothes, check air quality and apply different chemical safety rules. Nevertheless, Energy, Kaolin (especially sourced from UK) and

Potato Starch also deserve awareness since these inputs represent a significant contribution on the other three critical subcategories.

- In the cork industry, the raw material (cork) is the most critical input in the Raw Material's Extraction. Notice that all the cork used to model System 2 has 100% of Portuguese origin and thus, recommendations to improve the social performance should be applied in the Portuguese companies producing this raw material. Contrary to the other systems, the raw material (cork) is extracted manually, affecting principally the occupational health & safety of manual cutters. In this sense, it is important to extract cork from socially responsible sources that implement health and safety policies in all stages of the forest work and create training programs to improve both work productivity and safety.
- Lastly, in the wood industry, Formaldehyde resin is the most critical input in the Product's Manufacture, contributing to more than 70% of its total characterized value. Furthermore, Formaldehyde from Portugal has the highest contribution to this negative social impact, and thus, attention should be assigned to this country. As a result, companies from the wood industry producing this product might consider using other non-formaldehyde-based resins. Since regulations are limiting the maximum concentration of formaldehyde in the air, this can restrict the number of particle boards bonded with these resins used indoors and the number of particle boards which can be produced by a company.

## 5.3. Step 3 – Sustainability Assessment

This last step aims to assess the three systems in terms of their overall sustainability performance, considering the three pillars of sustainability: economic, environmental and social. Accordingly, Table 20 represents the main results from a social, economic, and environmental assessment for the three systems. The NPV and the Environmental single score (SS) values were retrieved form the work proposed by Santos et al. (2021).

Table 20: Main results from an economic, environmental and social assessment for the three systems

| | System 1 | System 2 | System 3 |
|---|---|---|---|
| **Quantity** | 529840.4kg | 2929.9kg | 223.7$m^3$* |
| **NPV (euros)** | 34213.1 | 353.1 | 6093.7 |
| **Environmental SS (Pt)** | 99172.4 | 21403.7 | 31602.8 |
| **Environmental Impact (Pt/euro)** | 2.9 | 60.6 | 5.2 |
| **Social SS (Pt)** | 18043220.8 | 411352.5 | 2019586.9 |
| **Social Impact (Pt/euro)** | 527.4 | 1164.9 | 331.4 |

*223.7 $m^3$ of particle boards = 150997.5 kg of particle boards (Santos et al., 2021).

As it can be observed, Table 20 contains values in red and green color, which correspond to the Systems with the worst and best performance for each parameter evaluated, respectively. When considering only the environmental dimension, it is possible to conclude that the production of natural cork stoppers from *Quercus suber* (System 2) has the better performance, since this system has the least Environmental SS (21403.7 Pt), considering the functional unit defined. However, this system has, at the same time, the lowest NPV (353.1 euros). In this sense, the ratio between the Environmental SS and the NPV was conducted. From this ratio, it is possible to conclude that the production of uncoated woodfree paper from *Eucalyptus Globulus* (System 1) generates the least environmental impact per euro of NPV (2.9 Pt/euro). On the other hand, the production of natural cork stoppers from *Quercus suber* generates the greatest environmental impact per euro of NPV (60.6Pt/euro).

Regarding the social dimension, System 2 is, once again, the better system from a social point of view, since it has the lowest Social SS obtained through the LCA software (411352.5 Pt), considering the functional unit defined. Nevertheless, when conducting the ratio between the Social SS and the NPV calculated, it is possible to conclude that this system has the higher social impacts per euro of NPV generated (1164.9 Pt/euro) and the production of particle boards from *Pinus Pinaster* (System 3) has the least social impacts per euro of NPV (331.4 Pt/euro). Concluding, from an environmental and economic point of view, System 1 (uncoated woodfree paper) has the better performance. However, from a social and economic dimension, System 3 (particle boards) has the best performance. Therefore, conclusions about the overall sustainability of the systems cannot yet be provided. In order to select the most sustainable system (i.e., the product with the better performance considering the three sustainability dimensions), it is necessary to perform the ratio expressed in Equation (2) of Section 4 of the present document. The values obtained for each system can be seen in Figure 30.

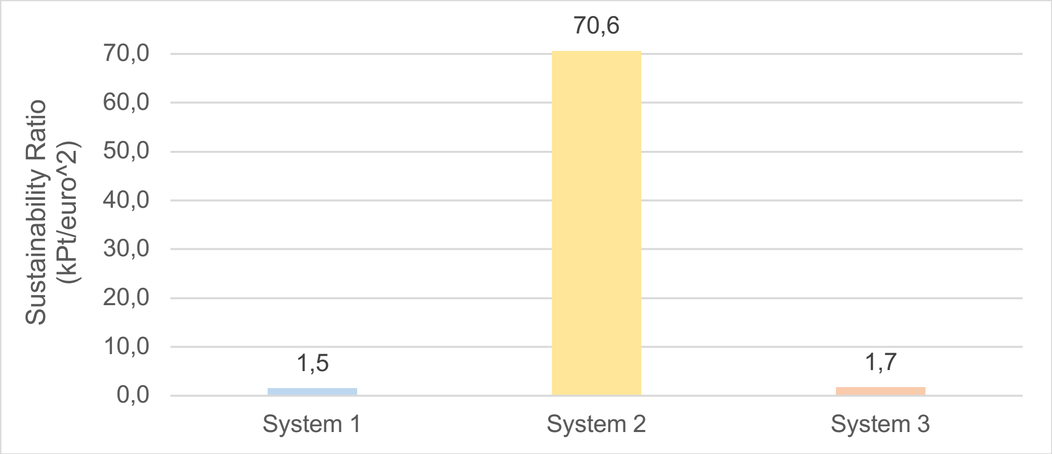


Figure 30: Sustainability Ratio comparison between the three systems

From the results of Figure 30, it is possible to conclude that System 1 has the better performance considering the three dimensions of sustainability, since this system has the lowest value obtained from the ratio of Equation (2) (1,5 $kPt/euro^2$). On the other hand, System 2 has the worst performance, and its value is significantly higher than both System 1 and 3. Therefore, on can conclude that planting *Eucalyptus globulus* in 1 hectare of forest land for 100 years to manufacture uncoated woodfree paper is the best option considering the three sustainability dimensions (economic, environmental and social).

# 6. Final Conclusions and Future Work

Although some research exists in the literature regarding the assessment of the environmental impacts of the forest sector through the ELCA, there is still no studies applying the SLCA to this sector. However, social aspects are increasingly recognized as an integral part of sustainable development and therefore, of sustainable management of forests and other natural resources. In this sense, this work aims to close this gap, applying the SLCA methodology proposed by the Guidelines through the SHDB to quantify the social impacts of the forest sector. Since this topic is still under research, every study regarding the application of this methodology to the forest sector is useful, in order to develop and refine the current SLCA methodology, as well as to obtain conclusions about the social sustainability performance of the companies operating in the forest industry.

For the purpose of this work, the forest sector was represented by the three most manufactured products from each major Portuguese forest-based industry, which are: uncoated woodfree paper from the pulp and paper industry (System 1), natural cork stoppers from the cork industry (System 2) and particle boards from the wood industry (System 3). The application of the SLCA methodology to these three systems allowed to conclude that, if the goal was to determine the best use, from a social point of view, that can be planted between *Eucalyptus globulus* to produce uncoated woodfree paper, *Quercus suber* to produce natural cork stoppers, and *Pinus pinaster* to produce particle boards, planting *Quercus suber* to manufacture natural cork stoppers will be the best option from a social perspective, since this system has the least Social single score obtained through the SLCA, considering the same system boundary functional unit. However, since the concept of sustainability comprises three different dimensions (environmental, economic and social), conclusions about the other two other pillars had to be made. Therefore, the work developed by Santos et al., (2021), which focused on the two other pillars of sustainability (environmental and economic) was used to support the present dissertation. The combination of the Environmental single score value obtained through the ELCA, the Social single score obtained in the SLCA, and the NPV calculated for the Economic Assessment, it was possible to conclude that planting *Eucalyptus Globulus* to produce uncoated woodfree paper is the best option from an overall sustainability assessment.

Besides these conclusions, some similarities between the three systems can be identified, and thus, conclusions about the social sustainability of the forest sector can be provided. The Health & Safety category is the most critical one, followed by the Labour Rights & Decent Work, which means that, to reduce social impacts, companies operating in the forest sector should address both issues and try to provide their workers the appropriate equipment and, also good and safe working conditions. Furthermore, the three systems share the same most impactful subcategories, which are: Injuries & Fatalities (IF), Occupational Toxic & Hazards (OTH) and Corruption (C). In this sense, when assessing and reporting the social impacts of the forest sector, governmental organizations and other stakeholders should focus their attention on these impact subcategories and try to demonstrate improvements in each one. Regarding the recommendations for each specific industry, it was observed that, in the pulp and paper industry, the consumption of water in the manufacturing process is the most critical input in this stage. In the cork industry, the raw material (cork) is the input with the highest contribution in the most critical life cycle stage (Raw Material's Extraction). Lastly, in the wood industry, the Formaldehyde resin used in the manufacturing process has a huge negative impact in the production of particle boards.

One of the challenges faced during the development of this work was the lack of case studies assessing the social sustainability dimension (especially for the forest sector), probably due to the lack of a widely accepted methodology for SLCA. In addition, for the fewer case studies assessing the social dimension, there was no coherence between the interpretation of the results obtained. Therefore, future work should be based on the development of a standardize methodology to quantify the social impacts throughout the entire supply chain of products and services, in order to have coherence between case studies. Furthermore, regarding the application of the SHDB in the SimaPro software, it would be interesting to improve the performance of this database by: (1) incorporating more countries; (2) disaggregating business sectors; (3) distinguish between production routes (e.g., mechanical vs. manual harvesting) and lastly, (4) separate countries into different regions, especially for the larger ones (e.g., Brazil or USA).

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# Appendix A – Social Hotspot Database

Table 21: Social Issues and respective weights used to calculate the Social Hotspot Index for each category (SHDB, 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 22: GTAP sectors and its respective codes (SHDB, 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 |
| 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 |

Table 22: GTAP sectors and its respective codes (SHDB, 2016) (Continuation)

| GTAP Sector Code | GTAP Sector | GTAP Sector Code | GTAP Sector | GTAP Sector Code | GTAP Sector |
|---|---|---|---|---|---|
| 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 – LCI Assumptions

## 1. Domestic production (DP) (percentage of production that is done by the own country)

Table 23: Domestic Production percentage, references, and additional notes

| Processes' Inputs | Domestic production (DP) | Reference | Notes |
|---|---|---|---|
| **Chemical inputs** | 39,4% | GEE, 2020b | CAE 20 Division: Production (P) in 2018 = 4824 M€, Imports (I) in 2018 = 7428 M€; DP=P/(P+I) |
| **Forest Inputs (pulpwood, cork and roundwood)** | 100,0% | - | Raw material is 100% of Portuguese origin (functional unit defined is the exploration of 1 ha of forest land in Portugal for 100 years). Therefore, DP=100% |
| **Electricity** | 91,7% | 1) IEA, 2016, pg.81-83;<br>2) IndexMundi, 2021 | 1) Production (P) = 52billion kwh, Imports (I) = ((9,4+0,9)/2 = 5,15billion kwh).*"Portugal’s electricity imports from Spain are highly volatile over the past decade, mainly because of the nature of hydro generation, with a high of 9.4 TWh in 2008 and a low of 0.9 TWh in 2014”;*<br>2) P = 56,9billion kwh, I = 4,616billion kwh;<br>DP=P/(P+I) (media of both sources 1 and 2). |
| **Diesel, Heavy fuel oil and Light fuel oil** | 0,0% | IEA, 2016, pg.16 | IEA is the International Energy Agency: *"Portugal has no fossil fuel production (including coal, **oil** and natural gas)."* |
| **Hard Coal, Lignite briquettes** | 0,0% | IEA, 2016, pg.16 | *"Portugal has no fossil fuel production (including **coal**, oil and natural gas)."* |
| **Natural Gas** | 0,0% | IEA, 2016, pg.16 | *"Portugal has no fossil fuel production (including coal, oil and **natural gas**)."* |
| **Water** | 100,0% | - | Considering that the Products' Manufacture stage is processed in Portugal |
| **Transport (lorry)** | 0,0% | IEA, 2016, pg.16 | Considering that this input is connected with diesel and oils, and Portugal has no fossil fuel production |
| **Transport (sea)** | 0,0% | IEA, 2016, pg.16 | Considering that this input is connected with diesel and oils, and Portugal has no fossil fuel production |

## 2. Countries of origin (import percentages) and domestic production percentage

Table 24: Countries of origin and domestic production for all the inputs required to model the three systems

| Processes' Inputs | Domestic Production | Import Country and Percentage* |
|---|---|---|
| **Alkylketene dimer sizing agent** | 39,37% | Austria (5,83%), Belgium (2,44%), Finland (1,01%), France (1,61%), Germany (11,12%), Italy (6,61%), Netherlands (9,94%), Spain (16,19%), UK (2,44%) |
| **Aluminium sulfate, powder** | 39,37% | Belgium (2,44%), China (1,01%), France (1,61%), Germany (11,12%), Italy (6,61%), Netherlands (9,94%), Spain (16,19%), UK (2,44%) |
| **Calcium carbonate, precipitated** | 39,37% | Belgium (2,29%), France (7,50%), Germany (3,21%), Italy (3,80%), Spain (41,21%), Vietnam (1,55%) |
| **Carbon dioxide, liquid** | 39,37% | China (2,13%), France (1,21%), Spain (54,96%) |
| **Chlorine dioxide** | 39,37% | France (13,35%), Spain (43,81%), Sweden (2,81%) |

| Processes' Inputs | Domestic Production | Import Country and Percentage* |
|---|---|---|
| **Citric acid** | 39,37% | Austria (15,16%), Belgium (12,51%), China (12,42%), France (0,65%), Germany (1,65%), Ireland (1,66%), Italy (1,01%), Netherlands (0,96%), Spain (10,59%), Sweden (1,17%), Thailand (2,61%) |
| **Coating powder** | 39,37% | Austria (26,62%), Belgium (1,62%), China (3,53%), Germany (5,88%), Italy (3,17%), Spain (15,58%), Sweden (2,83%) |
| **Cork** | 100,00% | - |
| **Diesel** | 0,00% | Belgium (11,26%), Brazil (1,34%), China (3,97%), Egypt (1,49%), France (2,24%), Greece (1,06%), Italy (1,74%), Netherlands (9,04%), Russia (11,41%), Saudi Arabia (3,64%), Spain (48,2%), United Arab Emirates (1,03%) |
| **Electricity** | 91,70% | Spain (8,30%) |
| **Ethanol** | 39,37% | Cyprus (7,05%), France (8,25%), Italy (0,99%), Spain (33,86%), Turkey (9,95%) |
| **Hard coal** | 0,00% | Colombia (1,71%), Italy (1,16%), Netherlands (1,25%), Spain (94,20%) |
| **Heavy fuel oil** | 0,00% | Belgium (11,26%), Brazil (1,34%), China (3,97%), Egypt (1,49%), France (2,24%), Greece (1,06%), Italy (1,74%), Netherlands (9,04%), Russia (11,41%), Saudi Arabia (3,64%), Spain (48,2%), United Arab Emirates (1,03%) |
| **Hydrochloric acid** | 39,37% | Belgium (5,85%), France (1,52%), Germany (3,17%), Netherlands (4,24%), Spain (40,19%), Sweden (5,65%) |
| **Hydrogen peroxide** | 39,37% | Belgium (8,40%), France (2,15%), Israel (4,88%), Netherlands (9,14%), Spain (29,32%), United Kingdom (6,49%) |
| **Kaolin** | 39,37% | France (2,04%), Germany (1,84%), Morocco (0,78%), Spain (9,73%), UK (43,65%), USA (1,69%) |
| **Light fuel oil** | 0,00% | Belgium (11,26%), Brazil (1,34%), China (3,97%), Egypt (1,49%), France (2,24%), Greece (1,06%), Italy (1,74%), Netherlands (9,04%), Russia (11,41%), Saudi Arabia (3,64%), Spain (48,2%), United Arab Emirates (1,03%) |
| **Lignite briquettes** | 0,00% | Poland (79,03%), Spain (20,97%) |
| **Lime** | 39,37% | Italy (0,99%), Spain (58,85%), |
| **Lubricating oil** | 39,37% | Belgium (10,70%), France (39,89%), Germany (2,61%), Italy (4,61%), Netherlands (2,24%) |
| **Magnesium oxide** | 39,37% | Austria (0,93%), Belgium (0,67%), China (3,78%), Greece (5,42%), Netherlands (6,94%), Spain (38,27%), UK (2,99%) |
| **Magnesium sulfate** | 39,37% | China (2,75%), Germany (24,06%), Greece (3,51%), India (4,58%), Italy (0,78%), Spain (24,08%) |
| **Malusil** | 39,37% | Belgium (2,52%), France (16,44%), Germany (7,05%), Italy (5,04%), Luxembourg (0,99%), Netherlands (0,64%), Poland (5,54%), Spain (18,84%), UK (1,55%) |
| **Melamine formaldehyde resin** | 39,37% | Belgium (1,70%), Denmark (2,69%), Egypt (1,79%), France (1,57%), Germany (42,19%), Italy (2,30%), Spain (7,54%) |
| **Methanol** | 39,37% | Netherlands (1,04%), Spain (2,89%), Trinidad and Tobago (54,77%), USA (1,71%) |
| **Methylene diphenyl diisocyanate** | 39,37% | Belgium (1,67%), Spain (7,48%), Germany (1,72%), Spain (48,34%) |
| **Natural gas, high pressure** | 0,00% | Spain (100%) |
| **Nitrogen, liquid** | 39,37% | Spain (59,47%), USA (0,81%) |
| **Oxygen, liquid** | 39,37% | Italy (3,86%), Spain (56,39%) |
| **Ozone, liquid** | 39,37% | Italy (6,46%), Spain (52,03%), USA (2,03%) |
| **Paraffin** | 39,37% | Belgium (1,87%), China (11,31%), Germany (4,98%), India (1,21%), Italy (0,67%), Malasya (7,54%), Netherlands (1,00%), South Africa (9,09%), Spain (20,71%), |

Table 24: Countries of origin and domestic production for all the inputs required to model the three systems (Continuation)

| Processes' Inputs | Domestic Production | Import Country and Percentage* |
|---|---|---|
| **Phenolic resin** | 39,37% | Belgium (25,62%), Brazil (1,90%), France (1,95%), Germany (0,62%), India (1,58%), Netherlands (3,23%), Poland (4,37%), South Korea (4,64%), Spain (15,78%) |
| **Polydimethylsiloxane** | 39,37% | Belgium (1,31%), China (1,80%), France (2,81%), Germany (12,36%), Hungary (0,72%), Italy (1,73%), Netherlands (10,31%), Spain (25,59%), UK (2,43%), USA (0,76%) |
| **Potato starch** | 39,37% | Belgium (2,95%), Denmark (4,15%), France (2,40%), Germany (8,60%), Netherlands (31,48%), Spain (10,36%) |
| **Printing ink** | 39,37% | France (4,67%), Germany (12,24%), Italy (8,08%), Netherlands (16,76%), Spain (8,83%), Switzerland (0,73%), Turkey (1,42%), UK (5,94%) |
| **Pulpwood** | 100,00% | - |
| **Quicklime, milled, loose** | 39,37% | France (0,86%), Spain (59,77%) |
| **Roundwood** | 100,00% | - |
| **Sodium chlorate, powder** | 39,37% | Canada (11,79%), France (31,09%), Spain (17,25%), |
| **Sodium chloride, powder** | 39,37% | Denmark (0,65%), France (1,82%), Israel (2,48%), Netherlands (22,48%), Spain (17,47%), Tunisia (1,29%), UK (12,86%) |
| **Sodium hydrogen sulfate** | 39,37% | France (1,29%), Germany (3,52%), Italy (1,12%), Netherlands (1,73%), South Korea (25,74%), Spain (14,16%), UK (12,72%) |
| **Sodium hydroxide** | 39,37% | Belgium (5,98%), China (3,48%), France (6,85%), Kuwait (2,39%), Netherlands (3,51%), Poland (9,90%), Russia (12,91%), Spain (12,68%), Sweden (0,62%), Taiwan (0,65%), UK (1,25%) |
| **Sodium hypochlorite** | 39,37% | Belgium (4,29%), China (12,57%), France (5,89%), Germany (10,65%), Italy (1,64%), Spain (12,87%), UK (12,41%) |
| **Sodium sulfate, anhydrite** | 39,37% | Belgium (5,32%), Bulgaria (16,44%), France (5,24%), Germany (7,24%), Spain (13,35%), Turkey (12,60%) |
| **Sulfur** | 39,37% | India (55,21%), Spain (4,71%), |
| **Sulfur dioxide, liquid** | 39,37% | China (0,65%), France (18,64%), Germany (3,36%), India (2,97%), Italy (2,73%), Netherlands (1,12%), Spain (29,45%) |
| **Sulfuric acid** | 39,37% | Belgium (1,26%), France (0,99%), Spain (54,34%), UK (3,38%) |
| **Transport, freight, lorry** | 0,00% | Belgium (3,38%), France (21,40%), Germany (13,13%), Italy (9,74%), Japan (3,39%), Netherlands (6,21%), Poland (2,14%), South Africa (3,00%), Spain (21,90%), Sweden (1,05%), Thailand (3,92%), Turkey (7,91%), UK (1,00%) |
| **Transport, freight, sea** | 0,00% | China (99,13%) |
| **Urea formaldehyde resin** | 39,37% | Germany (24,98%), Italy (7,80%), Spain (25,12%), Sweden (1,09%) |
| **Urea, as N** | 39,37% | Algeria (4,67%)**, Germany (15,09%), Latvia (1,84%), Netherlands (1,35%), Poland (1,43%), Russia (2,66%), Slovakia (1,09%), Spain (32,07%) |
| **Water** | 100,00% | - |

* This information was retrieved from the Atlas of Economic Complexity (Growth Lab of Harvard University, 2018).

** Since data for Algeria is not available in the SHDB, it was used its neighboring country Tunisia to approximate the social context of Urea production. The same approach was applied in (Thies et al., 2019).

## 3. Materials’ Prices used to model the three systems and respective references

Table 25: Prices and references of the different inputs used to model the three systems and its respective GTAP sector

| Processes' Inputs | Unit | Cost per unit (USD2011)* | Reference** | Notes | GTAP |
|---|---|---|---|---|---|
| **Alkylketene dimer sizing agent** | kg | 1,86 | Alibaba, 2021a | Minimium quantity of 1000kg | chm |
| **Aluminium sulfate, powder** | kg | 1,75 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Calcium carbonate, precipitated** | kg | 1,86 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Carbon dioxide, liquid** | kg | 0,15 | Air Liquide, 2021 | Information provided by phone call | chm |
| **Chlorine dioxide** | kg | 2,84 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Citric acid** | kg | 2,68 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Coating powder** | kg | 2,58 | LusoCopla, 2021 | Prices vary between 2 and 3 euros for a minimum quantity of 20kg (information provided by e-mail). | chm |
| **Cork** | kg | 1,51 | ICNF, 2020 | Price table by ICNF (Instituto da Conservação da Natureza e das Florestas) | frs |
| **Diesel** | kg | 1,38 | ICNF, 2018 | Report by ICNF (Síntese económica 2018) | p_c |
| **Electricity** | kWh | 0,12 | ICNF, 2018 | Report by ICNF (Síntese económica 2018) | ely |
| **Ethanol** | kg | 1,96 | 1) Global Petrol prices, 2021<br>2) Aqua-Calc, 2021 | 1) Assuming Spain prices, 2) density=0,79kg/L | chm |
| **Hard coal** | kg | 0,07 | BrasasVivas, 2021 | Information provided by phone call | coa |
| **Heavy fuel oil** | kg | 0,78 | Pordata, 2020 | Average price of fuel oil sold to the public in mainland Portugal | p_c |
| **Hydrochloric acid** | kg | 0,93 | Brenntag, 2021 | Quantity of 23kg (information provided by e-mail) | chm |
| **Hydrogen peroxide** | kg | 0,34 | INE, 2017 | Portuguese National Statistical Institute. Revenue (€) = 102 486 598; Quantity sold (kg) = 307 716 952; Price (€/kg) = Revenue/Quantity sold | chm |
| **Kaolin** | kg | 1,98 | Mistral Chemicals, 2021 | Quantity of 25kg - 48,05€ | nmm |
| **Light fuel oil** | kg | 1,45 | 1) Statista, 2020<br>2) NESTE, 2021 | 1) Average price of heating oil in Portugal. 2) Light fuel oil is a convenient heating fuel used to heat homes as well as industrial buildings. | p_c |
| **Lignite briquettes** | MJ | 0,03 | 1) TheOilPeople, 2021<br>2) Kpalo et al. (2020) | 1) Quantity of 10kg. 2) Calorific Value 14.5MJ/kg | coa |
| **Lime** | kg | 0,06 | Calcidrata, 2021 | Fertilizer made from calcium carbonate and calcium hydroxide. Quantity of 30kg – 1,77€ (information provided by phone call) | nmm |
| **Lubricating oil** | kg | 8,65 | FUCHS, 2021 | Quantity of 205L – 1 484,20€, density 0,864L/kg (information provided by e-mail) | chm |
| **Magnesium oxide** | kg | 1,91 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | nmm |
| **Magnesium sulfate** | kg | 1,01 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Malusil** | kg | 3,25 | Mistral Chemicals, 2021a | Quantity of 25kg - 78,82€ | chm |
| **Melamine formaldehyde resin** | kg | 1,74 | Alibaba, 2021b | Minimium quantity of 1000kg | chm |
| **Methanol** | kg | 1,16 | Brenntag, 2021 | Quantity of 20kg (information provided by e-mail) | chm |
| **Methylene diphenyl diisocyanate** | kg | 4,61 | Alibaba, 2021c | Minimium quantity of 100kg | chm |
| **Natural gas, high pressure** | m3 | 1,22 | DGEG, 2021 | Compressed natural gas | gas |
| **Nitrogen, liquid** | kg | 0,15 | Air Liquide, 2021 | Information provided by e-mail | chm |
| **Oxygen, liquid** | kg | 0,15 | Air Liquide, 2021 | Information provided by e-mail | chm |
| **Ozone, liquid** | kg | 0,26 | Linde, 2021 | Information provided by phone call | chm |

Table 25: Prices and references od the different inputs used to model the three systems and its respective GTAP sector (Continuation)

| Processes' Inputs | Unit | Cost per unit (USD2011)* | Reference** | Notes | GTAP |
|---|---|---|---|---|---|
| **Paraffin** | kg | 1,65 | SAPEQ QUIMICA 2021a | 1 600,00€ per tonne (information provided by e-mail) | chm |
| **Phenolic resin** | kg | 2,79 | Santos&Elvas, 2021 | Quantity of 5kg (information provided by phone call) | chm |
| **Polydimethylsiloxane** | kg | 13,39 | Mistral Chemicals, 2021b | Quantity of 5L – 62,93€, density = 0,97g/cm3 | chm |
| **Potato starch** | kg | 3,92 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Printing ink** | kg | 1,76 | INE, 2017 | Portuguese National Statistical Institute. Quantity sold (kg) = 91 063 441; Revenue (€) = 159 365 853; Price= Revenue/Quantity sold | chm |
| **Pulpwood** | m3 | 20,63 | ICNF, 2020 | Price of DAP 20;25 class (diameter) | frs |
| **Quicklime, milled, loose** | kg | 0,11 | Qualical, 2021 | Quantity per bag 40kg, price valid for a pallet containing 40 bags (information provided by e-mail). | nmm |
| **Roundwood** | m3 | 25,69 | ICNF, 2020 | Price of DAP (diameter) 30 class | frs |
| **Sodium chlorate, powder** | kg | 2,52 | N2O3, 2021 | Quantity of 5L - 30,36€, density=2,49kg/L | chm |
| **Sodium chloride, powder** | kg | 3,72 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Sodium hydrogen sulfate** | kg | 2,55 | Mistral Chemicals, 2021c | Quantity of 25kg | chm |
| **Sodium hydroxide** | kg | 1,14 | Brenntag, 2021 | Quantity of 38kg (information provided by e-mail) | chm |
| **Sodium hypochlorite** | kg | 3,51 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Sodium sulfate, anhydrite** | kg | 1,55 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Sulfur** | kg | 0,46 | SAPEQ QUIMICA, 2021b | Information provided by e-mail | chm |
| **Sulfur dioxide, liquid** | kg | 3,61 | Linde, 2021 | Information provided by phone call | chm |
| **Sulfuric acid** | kg | 2,01 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Transport, freight, lorry** | kgkm | 0,0002 | European Commision, 2005 | HDV (heavy duty vehicles) price | otp |
| **Transport, freight, sea** | kgkm | 0,00001 | European Commision, 2005 | Short sea shipping price | wtp |
| **Urea formaldehyde resin** | kg | 2,99 | Brenntag, 2021 | Quantity of 25kg (information provided by e-mail) | chm |
| **Urea, as N** | kg | 1,31 | INE, 2018b | Estatísticas Agrícolas. Statistics Portugal. Chart 10.4 - Annual prices of fertilizers. Urea - 128,97€/100kg | chm |
| **Water** | m3 | 1,80 | EPAL, 2020 | Non-domestic price (industrial, agricultural consumption) | wtr |

* The conversion to USD of 2011 was performed based on a CPI Inflation Calculator (CPI Inflation, 2021) and the Euro foreign exchange reference rates by the European Central Bank (European Central Bank, 2021), using the average exchange rate of the year in question.

** Whenever possible, the price was obtained by contacting directly with the suppliers of the materials in question (such as Brenntag, AirLiquide). The website Alibaba.com was used as a last resource.

### 4. End-of-life destinations' prices (recycling, landfill and incineration) for the three systems

Table 26: End-of-Life destinations' prices for the three systems

| End-of-Life destinations | Unit | Cost per kg (USD2011) | Reference | Notes | GTAP* |
|---|---|---|---|---|---|
| **Recycling Paper and Cardboard** | kg | 0,101 | Eurostat, 2020 | European Union (paper and board recycling): Jan2020 = 80€/tonne; May2020 = 124€/tonne. Therefore, (80+124)/2=102€/tonne. This price was applied for the recycling of UWF paper (System 1). | wtr |
| **Recycling Wood** | kg | 0,051 | PRO Europe, 2019; Eurostat, 2020 | It was observed that, in most of the European countries, recycling wooden packaging is 50% less expensive than recycling paper and cardboard packaging (Pro Europe, 2019). In this sense, the same trend was assumed in this study for particle boards (wood) and UWF paper (paper and cardboard). This price was used for the recycling of particle boards (System 3) and cork (System 2) since there was no information available for the costs of recycling cork. | wtr |
| **Landfill** | kg | 0,056 | CEWEP, 2020 | CEWEP is the Confederation of European Waste-to-Energy Plants. According to this source, the landfill tax rates in Europe vary from 5€/tonne to 107,32€/tonne. Therefore, (5+107,32)/2=56,16€/tonne. This price was apllied in the three systems. | wtr |
| **Incineration** | kg | 0,039 | CEWEP, 2020; APA, 2021 | APA is the Portuguese Environment Agency. It was assumed that the countries where the end-of-life of the three products takes place follow the same trend observed in Portugal, where the tax of incineration corresponds to 70% of the tax of landfill. This price was applied for the incineration in the three systems. | wtr |

* The GTAP sector "wtr" includes *"water supply, sewerage,* ***waste management*** *and remediation activities"* (GTAP, 2021).

# Appendix C – Life cycle stages

## (1) Raw Materials' Extraction

Table 27: Quantity of each tree species in each subregion of Portugal (Adapted from Santos et al., 2021)

| Source | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|
| | *(Eucalyptus globulus)* | | *(Quercus suber)* | | *(Pinus pinaster)* | |
| | Thousand hectares | % | Thousand hectares | % | Thousand hectares | % |
| **Subregions** | **845.01** | **100.00%** | **719.94** | **100.00%** | **713.25** | **100.00%** |
| Alto Minho | 25.45 | 3.01% | 0.13 | 0.02% | 24.28 | 3.40% |
| Alto Tâmega | 0.97 | 0.11% | 0 | 0.00% | 39.54 | 5.54% |
| Área Metropolitana do Porto | 63.78 | 7.55% | 0 | 0.00% | 11.63 | 1.63% |
| Ave | 18.38 | 2.18% | 0 | 0.00% | 13 | 1.82% |
| Cávado | 19 | 2.25% | 0.08 | 0.01% | 13.92 | 1.95% |
| Douro | 2.68 | 0.32% | 0.97 | 0.13% | 36.27 | 5.09% |
| Tâmega e Sousa | 29.63 | 3.51% | 0.03 | 0.00% | 16.31 | 2.29% |
| Terras de Trás-os-Montes | 4.23 | 0.50% | 14.56 | 2.02% | 24.92 | 3.49% |
| Beira Baixa | 65.24 | 7.72% | 20.94 | 2.91% | 72.54 | 10.17% |
| Beiras e Serra da Estrela | 7.15 | 0.85% | 4.33 | 0.60% | 61.42 | 8.61% |
| Médio Tejo | 71.04 | 8.41% | 15.49 | 2.15% | 51.81 | 7.26% |

Table 27: Quantity of each tree species in each subregion of Portugal (Adapted from Santos et al., 2021) (Continuation)

| **Source** | **System 1** | | **System 2** | | **System 3** | |
|---|---|---|---|---|---|---|
| | ***(Eucalyptus globulus)*** | | ***(Quercus suber)*** | | ***(Pinus pinaster)*** | |
| | **Thousand hectares** | **%** | **Thousand hectares** | **%** | **Thousand hectares** | **%** |
| Oeste | 36.48 | 4.32% | 0.57 | 0.08% | 17.26 | 2.42% |
| Região de Aveiro | 56.62 | 6.70% | 0 | 0.00% | 18.89 | 2.65% |
| Região de Coimbra | 119.58 | 14.15% | 0.05 | 0.01% | 87.77 | 12.31% |
| Região de Leiria | 50.13 | 5.93% | 0.13 | 0.02% | 66.92 | 9.38% |
| Viseu Dão Lafões | 33.5 | 3.96% | 0.1 | 0.01% | 83.36 | 11.69% |
| Área Metropolitana de Lisboa | 12.52 | 1.48% | 18.21 | 2.53% | 13.54 | 1.90% |
| Alentejo Central | 21.78 | 2.58% | 179.85 | 24.98% | 0.97 | 0.14% |
| Alentejo Litoral | 53.92 | 6.38% | 148.99 | 20.69% | 29.66 | 4.16% |
| Alto Alentejo | 43.59 | 5.16% | 113.92 | 15.82% | 11.72 | 1.64% |
| Baixo Alentejo | 12.3 | 1.46% | 73.24 | 10.17% | 0.75 | 0.11% |
| Lezíria do Tejo | 68.01 | 8.05% | 93.36 | 12.97% | 12 | 1.68% |
| Algarve | 29.03 | 3.44% | 34.99 | 4.86% | 4.77 | 0.67% |

Table 28: Quantity of raw material sourced from the different subregions for each of the three systems (Adapted from Santos et al., 2021)

| **Source** | **System 1** | | **System 2** | | **System 3** | |
|---|---|---|---|---|---|---|
| | **Quantity of pulpwood ($m^3$)** | **Distance (km)** | **Quantity of raw cork (kg)** | **Distance (km)** | **Quantity of roundwood ($m^3$)** | **Distance (km)** |
| **Subregions** | **1721.43** | **4150.60** | **14649.29** | **4764.00** | **436.37** | **4810.60** |
| Alto Minho | 51.85 | 195.00 | 2.65 | 81.90 | 14.85 | 200.00 |
| Alto Tâmega | 1.98 | 241.00 | 0.00 | 154.00 | 24.19 | 152.00 |
| Área Metropolitana do Porto | 129.93 | 120.00 | 0.00 | 0.00 | 7.12 | 124.00 |
| Ave | 37.44 | 179.00 | 0.00 | 57.70 | 7.95 | 174.00 |
| Cávado | 38.71 | 178.00 | 1.63 | 58.20 | 8.52 | 183.00 |
| Douro | 5.46 | 186.00 | 19.74 | 98.70 | 22.19 | 97.10 |
| Tâmega e Sousa | 60.36 | 151.00 | 0.61 | 42.20 | 9.98 | 145.00 |
| Terras de Trás-os-Montes | 8.62 | 289.00 | 296.27 | 211.00 | 15.25 | 200.00 |
| Beira Baixa | 132.91 | 137.00 | 426.09 | 255.00 | 44.38 | 171.00 |
| Beiras e Serra da Estrela | 14.57 | 138.00 | 88.11 | 234.00 | 37.58 | 125.00 |
| Médio Tejo | 144.72 | 95.50 | 315.19 | 202.00 | 31.70 | 182.00 |
| Oeste | 74.32 | 169.00 | 11.60 | 270.00 | 10.56 | 255.00 |
| Região de Aveiro | 115.34 | 63.40 | 0.00 | 69.30 | 11.56 | 84.90 |
| Região de Coimbra | 243.61 | 0.00 | 1.02 | 120.00 | 53.70 | 91.60 |
| Região de Leiria | 102.12 | 74.10 | 2.65 | 183.00 | 40.94 | 163.00 |
| Viseu Dão Lafões | 68.25 | 91.60 | 2.03 | 124.00 | 51.00 | 0.00 |
| Área Metropolitana de Lisboa | 25.51 | 203.00 | 370.54 | 309.00 | 8.28 | 290.00 |
| Alentejo Central | 44.37 | 244.00 | 3659.57 | 361.00 | 0.59 | 341.00 |
| Alentejo Litoral | 109.84 | 312.00 | 3031.64 | 419.00 | 18.15 | 399.00 |
| Alto Alentejo | 88.80 | 172.00 | 2318.04 | 290.00 | 7.17 | 260.00 |
| Baixo Alentejo | 25.06 | 344.00 | 1490.28 | 442.00 | 0.46 | 431.00 |
| Lezíria do Tejo | 138.55 | 137.00 | 1899.68 | 244.00 | 7.34 | 224.00 |
| Algarve | 59.14 | 431.00 | 711.97 | 538.00 | 2.92 | 518.00 |

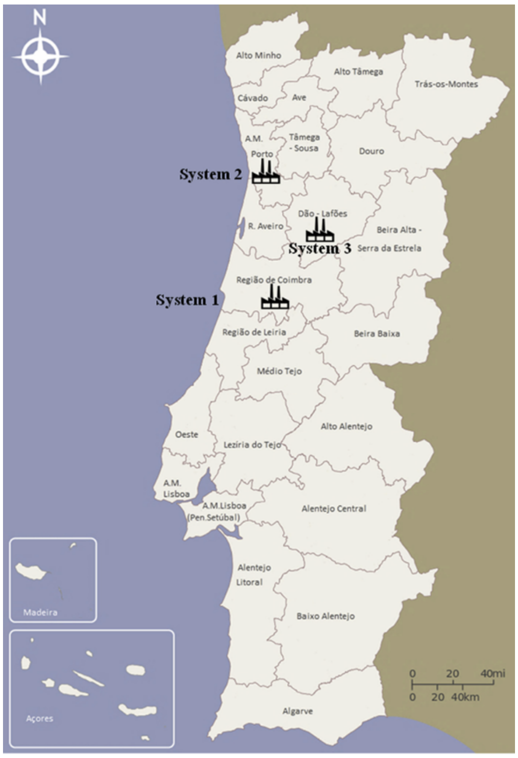

Figure 31: Location of the manufacturing facilities for the three forest products considered (Santos et al., 2021)

## (2) Products' Manufacture

### System 1 – Sulfate pulp

Table 29: Inventory data of System 1 for the Product's Manufacture stage (sulfate pulp)

| | Quantity | Unit | Price per Unit (USD 2011) | Total Price (USD 2011) | GTAP Sector | National Production Percentage | Import Percentage |
|---|---|---|---|---|---|---|---|
| **Sulfate pulp** | **18544.4** | **kg** | - | - | - | - | - |
| Aluminum sulfate | 7.2 | kg | 1.75 | 12.6 | chm | 39.4% | 60.6% |
| Calcium carbonate | 49.9 | kg | 1.86 | 92.7 | chm | 39.4% | 60.6% |
| Chlorine dioxide | 165.5 | kg | 2.84 | 469.6 | chm | 39.4% | 60.6% |
| Diesel | 3.8 | kg | 1.38 | 5.3 | p_c | 39.4% | 60.6% |
| Electricity | 566.1 | kWh | 0.12 | 68.5 | ely | 91.7% | 8.3% |
| Heavy fuel oil | 258.6 | kg | 0.78 | 200.6 | p_c | 0.0% | 100.0% |
| Hydrochloric acid | 18.0 | kg | 0.93 | 16.7 | chm | 39.4% | 60.6% |
| Hydrogen peroxide | 93.1 | kg | 0.34 | 31.5 | chm | 39.4% | 60.6% |
| Light fuel oil | 35.8 | kg | 1.45 | 51.8 | p_c | 0.0% | 100.0% |
| Lime | 2.8 | kg | 0.06 | 0.2 | nmm | 39.4% | 60.6% |
| Magnesium Oxide | 34.9 | kg | 1.91 | 66.6 | nmm | 39.4% | 60.6% |
| Magnesium sulfate | 3.1 | kg | 1.01 | 3.1 | chm | 39.4% | 60.6% |
| Malusil | 24.5 | kg | 3.25 | 79.6 | chm | 39.4% | 60.6% |
| Natural gas | 471.6 | m3 | 1.22 | 574.4 | gas | 0.0% | 100.0% |
| Oxygen | 266.7 | kg | 0.15 | 41.3 | chm | 39.4% | 60.6% |
| Ozone | 4.3 | kg | 0.26 | 1.1 | chm | 39.4% | 60.6% |

Table 29: Inventory data of System 1 for the Product’s Manufacture stage (sulfate pulp) (Continuation)

| | Quantity | Unit | Price per Unit (USD 2011) | Total Price (USD 2011) | GTAP Sector | National Production Percentage | Import Percentage |
|---|---|---|---|---|---|---|---|
| Quicklime | 34.8 | kg | 0.11 | 3.9 | nmm | 39.4% | 60.6% |
| Sodium chlorate | 57.2 | kg | 2.52 | 143.9 | chm | 39.4% | 60.6% |
| Sodium hydroxide | 293.8 | kg | 1.14 | 333.5 | chm | 39.4% | 60.6% |
| Sodium hypochlorite | 2.9 | kg | 3.51 | 10.2 | chm | 39.4% | 60.6% |
| Sodium sulfate | 6.6 | kg | 1.55 | 10.2 | chm | 39.4% | 60.6% |
| Sulfur | 0.02 | kg | 0.46 | 0.01 | chm | 39.4% | 60.6% |
| Sulfur dioxide | 0.8 | kg | 3.61 | 3.0 | chm | 39.4% | 60.6% |
| Sulfuric acid | 211.7 | kg | 2.01 | 426.0 | chm | 39.4% | 60.6% |
| Water | 533.0 | m3 | 1.80 | 961.7 | wtr | 100.0% | 0.0% |

### System 2 – Cork Planks

Table 30: Inventory data of System 2 for the Product’s Manufacture stage (cork planks)

| | Quantity | Unit | Price per Unit (USD 2011) | Total Price (USD 2011) | GTAP Sector | National Production Percentage | Import Percentage |
|---|---|---|---|---|---|---|---|
| **Cork Planks** | **10254.5** | **kg** | - | - | - | - | - |
| Electricity | 756.0 | kWh | 0.12 | 91.47 | ely | 91.7% | 8.3% |
| Polydimethylsiloxane | 692.0 | m3 | 1.22 | 842.67 | gas | 0.0% | 100.0% |
| Paraffin | 70.3 | m3 | 1.80 | 126.87 | wtr | 100.0% | 0.0% |

### System 2 – Natural cork stoppers production

Table 31: Inventory data of System 2 for the Product’s Manufacture stage (natural cork stoppers production)

| | Quantity | Unit | Price per Unit (USD 2011) | Total Price (USD 2011) | GTAP Sector | National Production Percentage | Import Percentage |
|---|---|---|---|---|---|---|---|
| **Natural cork stoppers production** | **3076.4** | **kg** | - | - | - | - | - |
| Electricity | 1282.5 | kWh | 0.12 | 155.19 | ely | 91.7% | 8.3% |
| Lubricating oil | 28.6 | kg | 8.65 | 333.83 | chm | 39.4% | 60.6% |
| Natural gas | 778.6 | m3 | 1.22 | 948.19 | gas | 0.0% | 100.0% |
| Sodium hydroxide | 102.5 | kg | 1.14 | 116.41 | chm | 39.4% | 60.6% |
| Hydrogen peroxide | 246.1 | kg | 0.34 | 83.36 | chm | 39.4% | 60.6% |
| Sodium hydrogen sulfate | 4.6 | kg | 2.55 | 11.77 | chm | 39.4% | 60.6% |
| Citric acid | 4.6 | kg | 2.68 | 12.38 | chm | 39.4% | 60.6% |
| Potato starch | 0.3 | kg | 3.92 | 1.15 | chm | 39.4% | 60.6% |
| Sodium chloride | 2.6 | kg | 3.72 | 9.52 | chm | 39.4% | 60.6% |
| Ethanol | 24.9 | kg | 1.96 | 48.75 | chm | 39.4% | 60.6% |
| Coating powder | 146.5 | kg | 2.58 | 377.95 | chm | 39.4% | 60.6% |
| Water | 89.7 | m3 | 1.80 | 161.75 | wtr | 100.0% | 0.0% |

## (3) Products’ Distribution

Table 32: Quantities and distances considered for the Products’ Distribution stage given the domestic markets of the three systems (Adapted from Santos et al., 2021)

| Market | Share | System 1 | | System 2 | | System 3 | |
|---|---|---|---|---|---|---|---|
| | | Quantity of UWF paper (kg) | Distance by truck (km) | Quantity of natural cork stoppers (kg) | Distance by truck (km) | Quantity of particle boards ($m^3$) | Distance by truck (km) |
| **Domestic Market** | **100%** | **41,886.77** | **4,150.60** | **2,685.80** | **4764.00** | **129.92** | **4810.60** |
| Alto Minho | 2.44% | 1023.39 | 195.00 | 65.62 | 81.90 | 3.17 | 200.00 |
| Alto Tâmega | 0.94% | 393.51 | 241.00 | 25.23 | 154.00 | 1.22 | 152.00 |
| Área Metropolitana do Porto | 17.56% | 7354.67 | 120.00 | 471.59 | 0.00 | 22.81 | 124.00 |
| Ave | 4.25% | 1778.18 | 179.00 | 114.02 | 57.70 | 5.52 | 174.00 |
| Cávado | 4.09% | 1714.47 | 178.00 | 109.93 | 58.20 | 5.32 | 183.00 |
| Douro | 2.05% | 857.54 | 186.00 | 54.99 | 98.70 | 2.66 | 97.10 |
| Tâmega e Sousa | 4.32% | 1809.55 | 151.00 | 116.03 | 42.20 | 5.61 | 145.00 |
| Terras de Trás-os-Montes | 1.17% | 491.25 | 289.00 | 31.50 | 211.00 | 1.52 | 200.00 |
| Beira Baixa | 0.89% | 372.28 | 137.00 | 23.87 | 255.00 | 1.15 | 171.00 |
| Beiras e Serra da Estrela | 2.36% | 986.56 | 138.00 | 63.26 | 234.00 | 3.06 | 125.00 |
| Médio Tejo | 2.20% | 922.34 | 95.50 | 59.14 | 202.00 | 2.86 | 182.00 |
| Oeste | 3.62% | 1515.39 | 169.00 | 97.17 | 270.00 | 4.70 | 255.00 |
| Região de Aveiro | 3.70% | 1548.22 | 63.40 | 99.27 | 69.30 | 4.80 | 84.90 |
| Região de Coimbra | 4.59% | 1923.34 | 0.00 | 123.33 | 120.00 | 5.97 | 91.60 |
| Região de Leiria | 2.94% | 1231.54 | 74.10 | 78.97 | 183.00 | 3.82 | 163.00 |
| Viseu Dão Lafões | 2.67% | 1118.68 | 91.60 | 71.73 | 124.00 | 3.47 | 0.00 |
| Área Metropolitana de Lisboa | 28.16% | 11795.22 | 203.00 | 756.32 | 309.00 | 36.59 | 290.00 |
| Alentejo Central | 1.66% | 696.90 | 244.00 | 44.69 | 361.00 | 2.16 | 341.00 |
| Alentejo Litoral | 0.98% | 409.32 | 312.00 | 26.25 | 419.00 | 1.27 | 399.00 |
| Alto Alentejo | 1.18% | 495.35 | 172.00 | 31.76 | 290.00 | 1.54 | 260.00 |
| Baixo Alentejo | 1.26% | 529.56 | 344.00 | 33.96 | 442.00 | 1.64 | 431.00 |
| Lezíria do Tejo | 2.47% | 1034.33 | 137.00 | 66.32 | 244.00 | 3.21 | 224.00 |
| Algarve | 4.50% | 1885.17 | 431.00 | 120.88 | 538.00 | 5.85 | 518.00 |

Table 33: Quantities and distances considered for the Products’ Distribution stage given the international markets of System 1 (Adapted from Santos et al., 2021)

| System 1 | Share | Quantity of UWF paper (kg) | Distance by truck (km) | Distance by ship (km) |
|---|---|---|---|---|
| **International Market** | **83.08%** | **405,391.88** | **18,050.00** | **29,180.11** |
| France | 12.74% | 62165.29 | 1586.00 | - |
| Germany | 10.93% | 53333.33 | 2633.00 | - |
| United States of America | 10.07% | 49136.93 | 110.00 | 5985.66 |
| Turkey | 9.56% | 46648.37 | 397.00 | 4215.15 |
| Spain | 8.67% | 42305.58 | 529.00 | - |
| Italy | 7.77% | 37914.00 | 2361.00 | - |
| United Kingdom | 4.92% | 24007.32 | 91.00 | 1783.48 |

Table 33: Quantities and distances considered for the Products' Distribution stage given the international markets of System 1 (Adapted from Santos et al., 2021) (Continuation)

| System 1 | Share | Quantity of UWF paper (kg) | Distance by truck (km) | Distance by ship (km) |
|---|---|---|---|---|
| Egypt | 4.41% | 21518.76 | 185.00 | 4533.70 |
| Algeria | 3.88% | 18932.60 | 50.00 | 1587.16 |
| Netherlands | 2.83% | 13809.09 | 2083.00 | - |
| Belgium | 1.82% | 8880.76 | 1909.00 | - |
| Morocco | 1.72% | 8392.80 | 135.00 | 824.14 |
| Switzerland | 1.45% | 7075.33 | 1861.00 | - |
| Saudi Arabia | 1.24% | 6050.63 | 474.00 | 10250.82 |
| Greece | 1.07% | 5221.10 | 3646.00 | - |

Table 34: Quantities and distances considered for the Products' Distribution stage given the international markets of System 2 (Adapted from Santos et al., 2021)

| System 2 | Share | Quantity of natural cork stoppers (kg) | Distance by truck (km) | Distance by ship (km) |
|---|---|---|---|---|
| **International Market** | **93.47%** | **228.12** | **10,566.00** | **70,564.90** |
| United States of America | 25.91% | 63.23 | 75.00 | 5956.03 |
| France | 25.38% | 61.94 | 1588.00 | - |
| Spain | 10.38% | 25.33 | 604.00 | - |
| Italy | 8.44% | 20.60 | 2363.00 | - |
| Mexico | 4.29% | 10.47 | 394.00 | 8502.53 |
| United Kingdom | 3.83% | 9.35 | 57.00 | 1674.21 |
| Chile | 3.76% | 9.18 | 125.00 | 12739.91 |
| Germany | 3.03% | 7.39 | 2635.00 | - |
| Australia | 2.95% | 7.20 | 285.00 | 19868.26 |
| Argentina | 2.42% | 5.91 | 45.00 | 10106.36 |
| South Africa | 1.57% | 3.83 | 532.00 | 11717.60 |
| Switzerland | 1.51% | 3.69 | 1863.00 | - |

Table 35: Quantities and distances considered for the Products' Distribution stage given the international markets of System 3 (Adapted from Santos et al., 2021)

| System 3 | Share | Quantity of particle boards (cubic meters) | Distance by truck (km) | Distance by ship (km) |
|---|---|---|---|---|
| **International Market** | **93.70%** | **87.89** | **7,632.00** | **8,450.68** |
| Spain | 55.88% | 52.41 | 601.00 | - |
| United Kingdom | 20.65% | 19.37 | 179.00 | 1674.21 |
| Morocco | 8.52% | 7.99 | 216.00 | 824.14 |
| Ireland | 2.27% | 2.13 | 140.00 | 1420.48 |
| France | 2.22% | 2.08 | 1495.00 | - |
| Israel | 1.62% | 1.52 | 189.00 | 4531.84 |
| Italy | 1.51% | 1.42 | 2270.00 | - |
| Germany | 1.03% | 0.97 | 2542.00 | - |