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

## Pulp and paper, cork and wood industries

Madalena Marques Veloso
*Department of Engineering and Management, Instituto Superior Técnico*
madalena.veloso@tecnico.ulisboa.pt

**Abstract**

The forest sector 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. Today, this sector plays an important role to achieve global sustainability at all levels, providing several economic and social benefits to communities. Due to its global importance, it is necessary to adopt sustainable practices along the entire forest supply chain, as well as to study and evaluate the environmental, economic and social impacts of this sector. Although some research exists regarding the assessment of both the environmental and economic dimensions of the forest sector, there is still lack of studies analysing the social sustainability of this sector. Therefore, this work aims to close this gap, applying the Social Life Cycle Assessment (SLCA) methodology through the Social Hotspot Database (SHDB) to quantify the social impacts of three forest wood products – uncoated woodfree paper, natural cork stoppers and particle boards – which will serve as a representation of the forest sector. The results indicates that 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 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 products was performed, concluding that the production of natural cork stoppers has the best social performance, considering the functional unit selected for this work.

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

## 1. INTRODUCTION

Forests are among the world's most productive land-based ecosystems and are essential to life on Earth. They provide solutions for addressing many development challenges including poverty eradication, food security and agriculture, energy, biodiversity conservation, and many others. In addition, 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 at all levels, and for this reason, forest resources must be preserved and protected against excessive exploitation or other disturbances (UNECE & FAO, 2009). In this context, the notion of sustainable forest management has emerged and became an extremely relevant topic both in forest and sustainability policies (Wolfslehner et al., 2005). Sustainable forest management (SFM) 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). 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 (Rametsteiner & Simula, 2003). Sustainability reporting is another method to internalize and improve an organisation's commitment to sustainable development, comprising the three sustainability dimensions: economic, environmental and social. Although these dimensions are equally important, the practice showed that environmental and economic dimensions have received more attention, while the social sustainability remained underexplored and less integrated (Dempsey et al., 2011). However, society is taking increasing interest in assessing social impacts of various activities and, due to the pressures imposed by different stakeholders, there is also a need of studying this sustainability component (Popovic et al., 2016).

The European forest sector comprises different forest-based industries, including the pulp and paper, the cork, and the wood industries. As in Europe, these industries are of extremely relevance for Portugal, being a fundamental source of wealth in economic terms (trough the creation of value and Gross Domestic Product) and social terms (through job creation). In 2018, the Portuguese forest-based industries represented a business volume of, approximately, 10 billion euros, which corresponds to 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, about 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). The most manufactured products by these industries 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 (ICNF, 2018).

Despite its social and economic benefits, the forest-based industries are also responsible for social impacts that need to be properly studied and quantified. However, little attention has been given to the social impacts of the forest sector (Santos et al., 2019). Therefore, it is necessary to analyse the social effects of these forest-based industries since they provide numerous benefits for the society and contribute for the creation of several jobs.

Different methods, principles and tools to assess social impacts have been developed in the last decades. Other initiatives focus on corporate social responsibility, including ISO 26000: Guidance on Social Responsibility and Social Accountability 8000 (SA 8000), which is an auditable social certification standard. While these guidance documents are helpful, they are often interpreted according to the stakeholder and the context in which they are applied (Sutherland et al., 2016). In this sense, as part of the Life Cycle Sustainability Assessment (LCSA) tools, Social Life Cycle Assessment (SLCA) is presented as the most effective technique to assess the social impacts of products throughout their life cycles (Macombe et al., 2018). 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"*. An important achievement in the development of SLCA was the publication of the United Nations Environment Program/Society for Environmental Toxicology and Chemistry (UNEP/SETAC) Guidelines on SLCA. The document constitutes a generic and effective framework based on two dimensions: stakeholders and impact categories (Benoît et al., 2010). 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, Consumers, and Value chain actors. The second one, the impact categories, are: Human Rights, Working conditions, Health and Safety, Cultural Heritage, Governance and Socioeconomic contribution, which are further divided into a total of 31 impact subcategories. Compared to other tools assessing social impacts, SLCA focuses on a product (or service) level and considers the entire life cycle and a broader range of stakeholders (UNEP, 2009).

SLCA is based on the Environmental Life Cycle Assessment (ELCA) and originally, it was conceived as a social complement to ELCA (Garrido, 2017). Both methodologies share the same framework (ISO 14040), comprising four main steps: (1) Goal and scope definition; (2) Life cycle inventory analysis (LCI); (3) Life cycle impact assessment (LCIA); and (4) Interpretation. Depending on the goal and scope of the study, an SLCA study can be based on generic and/or site-specific data (Du et al., 2019).

Data availability is recognized as a critical factor for the development of SLCA (SHDB, 2019). A typical product system can contain several unit processes; thus, it is not practical to collect specific data at every organization along a supply chain, especially considering the increasing globalization of supply chains. However, the application of a database can simplify this task significantly by revealing where in the supply chain attention should be focused (Du et al., 2019). Two databases have been developed specifically for the purpose of supporting SLCA: the Social Hotspots Database (SHDB) and the Product Social Impact Life Cycle Assessment (PSILCA). For every country-specific sector considered in a given product system, both databases will evaluate social data according to levels of social risk. 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 (Garrido, 2017). Risk levels and characterization factors are represented in Table 1.

Table 1: Risk levels and characterization factors for the SHDB and PSILCA

| 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 |

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 conversation rule, these levels of social risk can be converted into a single unit, medium risk hours equivalent (Mrheq), which allows overall aggregation of different risk levels (Garrido, 2017).

According to Ramos Huarachi et al. (2020), the SHDB is the most used SLCA database, being applied in several products and industry sectors. For example, Benoit-Norris et al. (2012) presented an overview of the SHDB development and features, conducting a pilot student on a strawberry yoghurt. Lehmann et al. (2013) discussed the applicability of SLCA using two case studies of technologies in water supply and fuel production, extracting data from the SHDB. Martínez-Blanco et al. (2014) compared three types of fertilizers, using data from the SHDB. Du et al. (2019) analysed a case study of sugarcane production in Brazil, exploring how the results of a screening SLCA can be improved. Thies et al. (2019) analysed the social hotspots in the supply chain of lithium-ion batteries using data from SHDB. However, to the author best knowledge, there are still no studies found on the literature applying the SLCA combined with the SHDB to assess the social impacts of the forest sector and its forest products.

In this sense, the aim of this paper is to study the social sustainability dimension of the forest-based industries as well as to quantify the social impacts of this sector through the application of the SLCA methodology proposed by the Guidelines combined with the SHDB. For the purpose of this study, the forest sector will be represented by the three most manufactured products from each major 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.

The remaining of this paper is organized into three different sections. In section 2, the methodology applied in this research is explained in detail. Section 3 analyses the main results of this study, presenting recommendations for the companies to improve their social performance. Finally, in section 4, the main conclusions and some suggestions for the future work are provided.

## 2. METHODOLOGY

This section provides a description of each step of the research methodology applied in this work. The first four sub steps belong to the SLCA methodology.

### Step 1.1 – Goal and scope definition

The first step of an LCA study, Goal and Scope Definition, consists of establishing the LCA goal and characterizing the system(s) under analysis through the definition of the functional unit, activity variable and system boundary (UNEP, 2009). The functional unit provides a point of reference to quantify the magnitude of the system associated with the product considered and allows a comparison between different products. The activity variable is a variable representing a quantifiable activity that can be measured at each life cycle stage (or process). The Guidelines suggest two different activity variables: added value and working time, being the last one the most frequently used (Garrido, 2017).

### Step 1.2 – Life cycle inventory analysis (LCI)

This second step aims to collect and organize data required to introduce in the LCA software for the following steps, which should be quantitatively related to the functional unit established (Santos et al., 2021). The SHDB, which will be applied in this study, requires the following data: (1) a list of the materials used to produce the three products under study; (2) which of the 57 GTAP sectors the materials belong to; (3) in which country were the materials sourced from (both domestic and international market); and (4) what is the cost of the materials (in USD 2011) (SHDB, 2019). The output of this step is an inventory list with all the information required to model the three systems throughout their entire life cycles.

### Step 1.3 – Life cycle impact assessment (LCIA)

In the third step of an LCA study, the inventory collected in the previous step is converted into social impacts using LCIA methods. The three systems were modelled using a LCA software, namely SimaPro. This software is compatible with the selected database and the method chosen is the Social Hotspot 2019 Subcategories & Categories Method with Damages, based on a recommendation by the Pré Consultancy (PRé Sustainability, 2019). This method has five categories which cover a range of relevant subcategories of impact (also known as social themes), being represented in Table 2.

Table 2: Impact categories and subcategories included in the method (SHDB, 2019)

| Impact Categories | Impact Subcategories |
|---|---|
| **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. The analysis of the results in this study will mainly identify critical impact categories, critical impact subcategories, critical life cycle processes, and lastly, social hotspots. The interpretation will focus on explaining these results, discuss root causes and propose recommendations for the problems identified. In this step, a Pareto analysis will be applied to determine the most critical subcategories for each system. This principle states that 80% of the effects arise from 20% of the causes.

### Step 2 – Comparison of systems

In this second main step, the results obtained from the SLCA for the three systems are compared to select the system with the better social performance considering the functional unit selected for this study.

### Step 3 – Sustainability assessment

This last step 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 dimensions and thus, it is important to assess the other two pillars. For this purpose, the work proposed by Santos et al. (2021), which focused on the assessment of the economic and environmental pillars of these three products will be used to complement the present study. The choice of the most sustainable product will be based on the following Equation (1):

$$Sustainability\ Ratio\ (kPt/euro^2) = \frac{SS_{social}}{NPV} \times \frac{SS_{environemntal}}{NPV} \quad (1)$$

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

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

$NPV$ = Net present value (euro)

The most sustainable product will have the lowest Sustainability Ratio identified in Equation (1) since the Single Score (SS) obtained in both the SLCA and ELCA should be minimized (numerator) and, at the same time, the NPV obtained for each system (denominator) should be maximized.

## 3. RESULTS ANALYSIS AND DISCUSSION

### 3.1. SLCA application

### 3.1.1 Step 1.1 – Goal and scope definition

The main goal for conducting this study is to evaluate the potential social impacts caused by the forest sector, which will be represented by the three most manufactured products from each major forest-based industry. In addition, one of the objectives for conducting this study through a SLCA is to determine the best use, from a social perspective, that can be given to land between the plantation of *Eucalyptus globulus* to produce uncoated woodfree paper (System 1), the plantation of *Quercus suber* to produce natural cork stoppers (System 2), and the plantation of *Pinus pinasters* to produce particle boards (System 3). These three products under study have different functions and thus, identifying a functional unit is not an easy task. However, they are all forest wood products, which means they all share the same primary raw material, which is wood. In this sense, the functional unit selected is the exploration of 1 hectare of forest land in Portugal for 100 years.

In order to compare the three systems, the same boundary must be considered. The final products are very different at each life cycle stage and thus, a cradle to grave boundary was selected. The life cycle modelled for the three systems is represented in Figure 1.

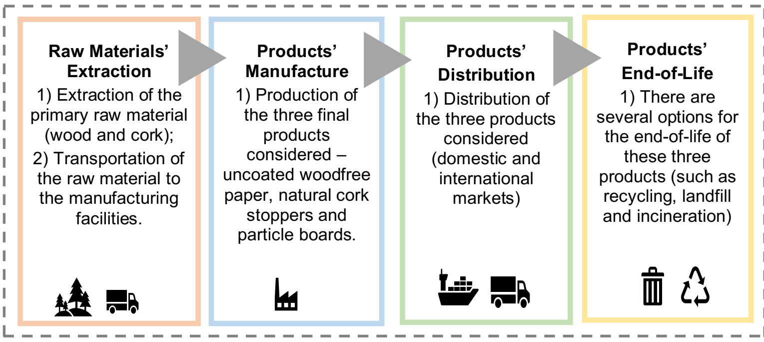


Figure 1: Life cycle modelled for the three systems

### 3.1.2 Step 1.2 – Life cycle inventory (LCI)

As it was discussed in the previous step, the functional unit defined is the exploration of 1 ha of forest land in Portugal for 100 years. This functional unit 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 specie considered. Therefore, in order to collect the data required, it is firstly necessary to determine: (1) the amount of pulpwood, cork and roundwood that can be harvested from 1 ha of forest land in Portugal for 100 years; (2) the quantity of each product (UWF paper, natural cork stoppers and particle boards) that can be produced using the previous raw material calculated. Accordingly, Table 3 summarizes all these quantities, which were retrieved from the article proposed by (Santos et al., 2021).

Table 3: Amount of raw material harvested, and quantity of product obtained considering the functional unit defined

| | | Quantity | Unit |
|---|---|---|---|
| System 1 | Pulpwood | 1721.43 | cubic meters |
| | Uncoated woodfree paper | 529840.41 | kilograms |
| System 2 | Cork | 14649.29 | kilograms |
| | Natural cork stoppers | 2929.86 | kilograms |
| System 3 | Roundwood | 382.01 | cubic meters |
| | Particle boards | 223.72 | cubic meters |

The remaining of this step is organised according to the four life cycle stages identified in the first step, which are: (1) Raw Materials' Extraction; (2) Products' Manufacture; (3) Products' Distribution; and (4) Products' End-of-Life.

*(1) Raw Materials' Extraction*

The first life cycle stage consists of extracting the primary raw material used in the three systems. This stage also includes the transportation of the raw material to the facility where the product is manufactured.

The process to obtain the transportation distance between the regions where the raw material is harvested and the facility where the product is manufactured follows the same approach used in Santos et al. (2021) to model the ELCA of the same three products. *Eucalyptus globulus*, *Quercus suber* and *Pinus pinaster* trees exist in 23 different subregions of mainland Portugal. The quantity share of each tree species that exists in these different subregions were multiplied by the total volume of pulpwood (1721.43m3), cork (14649.29kg) and roundwood (382.01m3) to determine the quantity of raw material provided by each subregion.

The subregion with the higher number of companies manufacturing each product considered was assumed to be where the facility is located. The distance from the 23 subregions and the respective subregion where the facility was assumed to be located represent the transportation included in this stage for each system.

*(2) Products' Manufacture*

The second life cycle stage consists in the production of the three products considered. In order to be produced, each product requires different materials (e.g., chemicals, electricity, water). The materials' prices were retrieved from different sources, such as statistics platforms, websites of relevant activities and by contacting directly with the suppliers of the inputs in question. In addition, it is also required data about where the material is sourced from, which was retrieved from the Atlas of Economic Complexity (Growth Lab of Harvard University, 2018) and only countries that contributed more than 1% of the total imports of each material were considered.

*(3) Products' Distribution*

The third stage consists of distributing the three final products considered. Therefore, it is necessary to determine the quantity of each product that are distributed to both national and international market, and the distances travelled to guarantee this distribution. The values used to model this stage follows the same approach as the values obtained in the article developed by Santos et al. (2021).

For the domestic market, 23 points of demand were considered which correspond to the 23 subregions where the raw material is harvested. The demand of each subregion was assumed to be proportional to its population, and the transportation mode considered was road. For the international market, it was firstly necessary to determine the countries to which the three forest wood products are exported. For this purpose, 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. Both road and maritime transportation were considered for the distribution in the international market.

*(3) Products' End-of-life*

The final life cycle stage consists in the end-of-life phase of the three products, which can be recycling; incineration (combusted with energy recovery); and landfill. Therefore, it is necessary to know the amount of product that goes to each end-of-life destination. The percentage of product that goes to each destination was retrieved from the article proposed by Santos et al. (2021). The end-of-life cost was sourced from statistics platforms and websites of relvant activities. The GTAP sector, "wtr", includes *"water supply, sewerage, waste management and remediation activities"*. The end-of-life stage was considered to take place in the respective countries where the product is sold (both domestic and international market). Table 4 summarizes the inventory data required to model this step.

Table 4: 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 m3 | 34.150 | wtr |
| Incineration | 15.8% | 35.35 m3 | 26.323 | wtr |
| Landfill | 67.5% | 151.01 m3 | 37.605 | wtr |

### 3.1.3 Step 1.3 – Life cycle impact assessment (LCIA)

The first output of the software is the characterized values of the different subcategories included in the method selected. All these values share the same unit of measurement, which is medium risk hours equivalent (Mrheq). However, each process is different in its risks 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. Therefore, the next step will conduct an interpretation of the results, identifying the most critical risks in each system.

### 3.1.4 Step 1.3 – Interpretation

**System 1 – Uncoated woodfree paper**

The interpretation of the results obtained starts with identifying the most critical categories for each system. Accordingly, Figure 2 represents the contribution of each category to the SS of System 1.

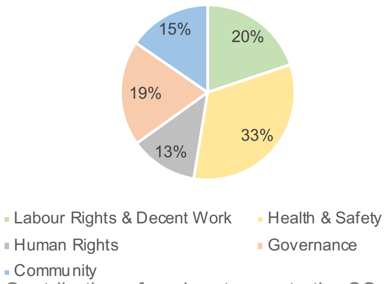


Figure 2: Contribution of each category to the SS of System 1

From Figure 2, it is possible to observe that more than a half percent of the total SS 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 promotion of physical and social well-being of workers and the protection of workers from factors adverse to health. The second one, Labour Rights & Decent work, consists of four strategic objectives: 1) full and productive employment; 2) fundamental principles and rights at work; 3) social protection; and 4) promotion of social dialogue (ILO, 2008). In this sense, one starting point to improve the social performance of the pulp and paper companies should be based on the previous mentioned objectives.

The next step is to identify the most critical subcategories for System 1. Accordingly, a Pareto analysis considering the normalized values of the different impact subcategories was conducted to determine the most critical ones. From this analysis, it was possible to conclude that the five most impactful subcategories for this system, corresponding to 20% of the causes, are: Injuries & Fatalities (IF), Occupational Toxic & Hazards (OTH), Corruption (C), Legal System (LS) and High Conflict Zones (HCZ). The results interpretation will focus on the five most critical subcategories for each system.

After determining the most critical subcategories, it is important to identify the life cycle stage which is contributing the most to the negative social impacts of these subcategories. Accordingly, Figure 3 represents the contribution of each stage to the five most critical subcategories for System 1.

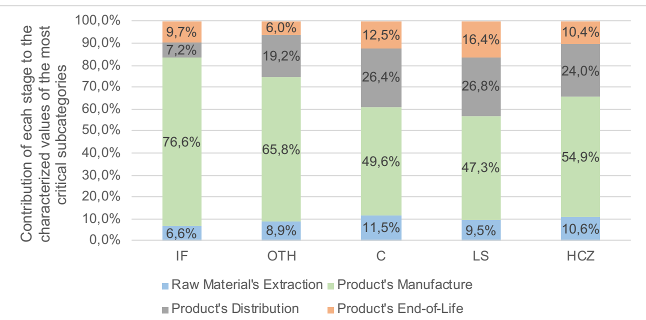


Figure 3: Contribution of each stage to the five most critical subcategories for System 1

As it can be observed from Figure 3, the Product's Manufacture is the life cycle stage that contributes more to the social impacts of all these subcategories. Especially in the most impactful subcategory, Injuries & Fatalities (IF), this stage has the highest share of contribution, representing 76.6% of its total characterized value. Since this stage is the most critical one, it is important to identify the input which is contributing more to the characterized value of this stage, in order to provide more specific recommendations for the companies in the pulp and paper industry to improve their social performance. Accordingly, Figure 4 represents the contribution of each input to the Product's Manufacture stage in the five most critical subcategories.

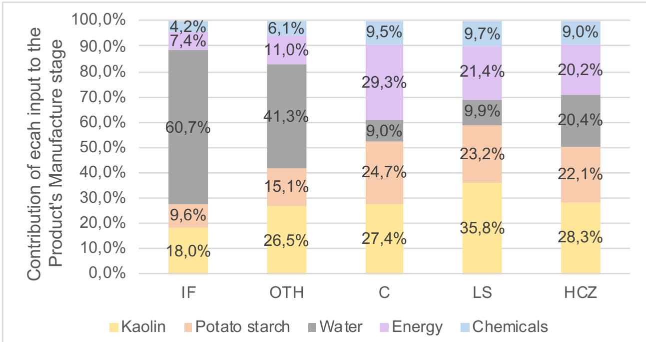


Figure 4: Contribution of each input to the Product's Manufacture stage of System 1

In the most critical subcategory (IF), it is possible to observe from Figure 4 that the consumption of Water is the input with the greatest contribution, representing 60.7% of its total characterized value. The assessment of the Injuries & Fatalities (IF) 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, the utilities sector is the industry of higher risk for serious injuries and fatalities, being water the most critical utility, followed by electricity and gas. 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 (OTH), the Water input is once again the most critical one, representing 41.3% of the total characterized value of this subcategory. The Occupational Toxic & Hazards (OTH) 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). Therefore, several preventive measures should be adopted by the Portuguese water treatment organisations, such as: (1) use appropriate ear protection and appropriate clothes; (2) check air quality and, if it is necessary, exhaust ventilation; (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 (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. Transparency in the energy industry can be improved by privatizing electricity distribution and encouraging electricity customers to demonstrate their frustration with inadequate service (Lovei & McKechnie, 2000).

Finally, in both the Legal System (LS) and High Conflict Zones (HCZ) subcategories, Kaolin is the most critical input. This chemical is widely used in the pulp and paper industry both as a filler in the bulk of the paper and to coat its surface. The LS subcategory is mainly based on the risk of fragility in legal system for each country specific sector, considering different indexes for this evaluation (such as CIRI Human Rights Index – Independent Judiciary). The HCZ subcategory aims to assess the potential of a nation to have conflicts of interests both societal and interstate welfare and its data indicators are the number of conflicts and its intensity in each country sector, number of refugees, among others (SHDB, 2019). After analysing this input into detail, it was observed that the largest share of social impacts comes from the United Kingdom (UK) in both subcategories and thus, it is important to impose pressures on the UK suppliers of Kaolin to improve their legal system and to reduce the number of conflicts that occur in this country specific sector.

**System 2 – Natural cork stoppers**

Now, moving for System 2, it is firstly necessary to determine the most critical categories for this system. In this sense, Figure 5 represents the contribution share of each category to the SS of System 2.

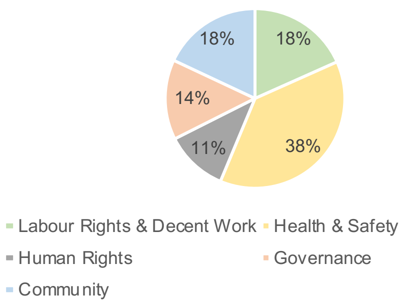


Figure 5: Contribution of each category to the SS of System 2

From Figure 5, 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 (18%), Governance (14%) and Human Rights (11%). These five categories are now disaggregated into different impact subcategories and a Pareto analysis applied to the normalized values of these subcategories was conducted. From this analysis, it was possible to conclude that the five most impactful subcategories, corresponding to 20% of the causes are: Injuries & Fatalities (IF), Occupational Toxic & Hazards (OTH), Corruption (C), Migrant Labour (ML) and Children Out of School (CoS). As it was observed for System 1, the three most critical subcategories remain the same, which are: IF, OTH and C. However, the fourth and fifth subcategories changed. ML, the fourth one, 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 human traffic. The fifth one, CoS, assesses the percentage of children who are not attending the primary schooling. Ensuring that all children go to school and their education is of good quality are keys to preventing child labour (SHDB, 2019).

The next step in the results interpretation is to identify the life cycle stage which is contributing more to the social impacts of these subcategories. Accordingly, Figure 6 represents the contribution of each stage to the characterized values of the five most critical subcategories for System 2.

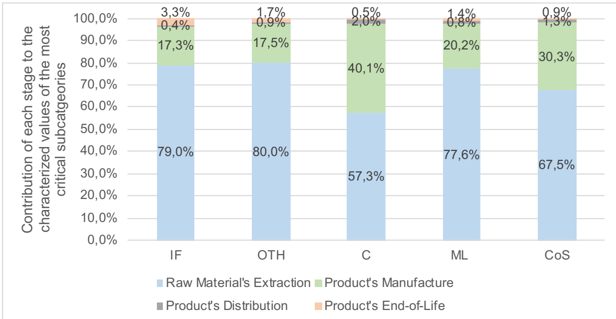


Figure 6: Contribution of each stage to the five most critical subcategories for System 2

As it can be observed from Figure 6, the Raw Material's Extraction is the most critical stage in the life cycle of natural cork stoppers. Therefore, a detailed analysis will be conducted to this stage, in order to determine the most critical input. The Raw Material's Extraction in this system only includes two inputs: the raw material (cork) and the transport to the facility. After analysing this stage into detail, it was possible to conclude that the 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 to 96.1% and 95.0% of the characterized value of each subcategory, respectively. This result means that there is a high risk in the cork extraction 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 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.

Notice that all the cork used to model this system comes from Portugal since the functional unit selected is the exploration of 1 ha of forest land in Portugal for 100 years. Moreover, contrary to System 1 and 3, the extraction of raw material is performed manually, and this may lead to different and generally higher social impacts than if it was done using machines. Du et al. (2019) compared the social impacts between mechanical and manual harvesting, concluding that mechanical harvesting has lower impacts in most social themes. In particular, the Health & Safety is a critical concern for manual harvesting, mainly due to the pressures imposed to achieve a high productivity. Furthermore, manual cutters are usually paid by productivity rather than a fixed wage and this often motivates them to work beyond their physical limits. Therefore, 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 (Souza et al., 2018). Nevertheless, the SHDB does not allow to distinguish between manual and mechanical harvesting, being one of this study's limitations, which will be further explored.

Concluding, since the Raw Material's Extraction is performed manually and this process is the most critical, companies in the cork industry should be aware of where their cork is being extracted and what are the working conditions on this stage. The main actions for these companies to improve their social performance are: (1) to promote better working conditions; (2) to implement health & safety policies in all stages of forest work, (3) to improve the overall accident rate; and (4) to create training programs that target low skilled jobs to improve both worker productivity and safety (ILO, 2019).

**System 3 – Particle boards**

Finally, moving for the last system, the first step consists of identifying the most critical categories to the SS of this system.

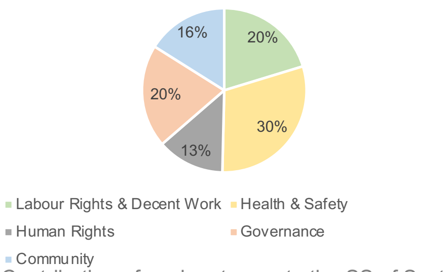

Figure 7: Contribution of each category to the SS of System 3

From Figure 7, it is possible to observe that the Health & Safety is the most critical category, representing 30% of the total SS of System 3, followed by both Labour Rights & Decent Work and Governance (20%), Community (16%) and Human Rights (13%). These five categories are now disaggregated into different subcategories of impact and a Pareto analysis was conducted to the normalized values of each subcategory, in order to determine the most critical ones. The result of this analysis reveals that the five most impactful subcategories are: Injuries & Fatalities (IF), Occupational Toxic & Hazards (OTH), Corruption (C), Legal System (LS) and High Conflict Zones (HCZ). Notice that both top impactful subcategories (IF and OTH) belong to the category of Health & Safety, which is the most critical one for the three systems. Therefore, one can conclude that this category is a major concern for the forest sector.

The next step is to identify the most critical life cycle stage in these five subcategories. Accordingly, Figure 8 represents the contribution of each stage to the five most impactful subcategories for System 3.

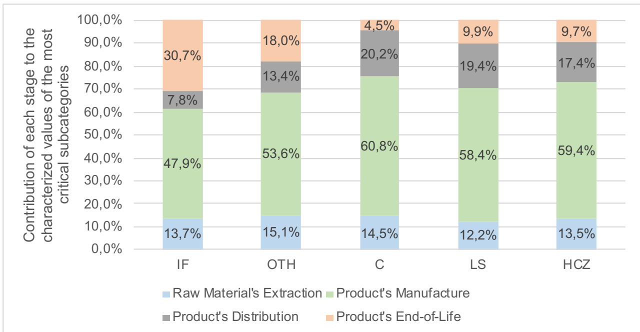

Figure 8: Contribution of each stage to the five most critical subcategories for System 3

Form the analysis of Figure 8, it is possible to observe that the Product's Manufacture stage is the most critical in the five subcategories and thus, it is important to identify the input materials which are contributing more to the social impacts of this stage. In this sense, Figure 10 represents the contribution of each input to the characterized value of the Product's Manufacture stage in each critical subcategory.

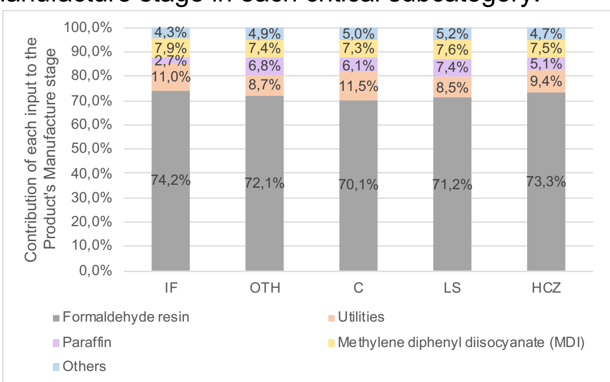

Figure 9: Contribution of each input to the Product's manufacture stage of System 3

From Figure 9, 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 the five subcategories analysed. Formaldehyde resin is a colorless and flammable chemical that is used in the production of glues for the manufacturing of pressed wood products. 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: Germany, Italy, Spain and Sweden (Growth Lab of Harvard University, 2018). After analysing this input into detail, it was observed that Formaldehyde resin from Portugal represents the highest negative social impact in these five subcategories (around half of the social impacts) and thus, attention should be assigned to this country.

It is important to refer that Formaldehyde is a suspected human carcinogen that is linked to both nasal and lung cancer. Due to the negative effects on the workers' health, the authorities established the Permissible Exposure Limits for formaldehyde at the workplace, which is 0.75 ppm, measured as an 8-hour time weighted average. This imposed limit 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. 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 LCA 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 to prevent skin and eye contact (OSHA, 2002).

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. For example: (1) data on sector level are rather roughly divided and for some sectors or countries there is no available data; (2) indicators in the SHDB are based on countries since the statistics used are often collected on a country basis; (3) the social categories and social themes selected in the SHDB are generic and not specifically adapted to the forest-based industries under study; and (4) the database has limited ability to distinguish between different production routes, such as manual and mechanical harvesting. 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 accurate results.

Another important source of limitations is due to some 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 time-consuming process to collect data on a country level for all the 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). In this sense, a sensitivity analysis was conducted to understand how the results of this study are affected by the uncertainty of the prices used. 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 in the most impactful stage. Results from this analysis indicates that, even if the prices of the most critical inputs (Water for System 1, Cork for System 2 and Formaldehyde resin for System 3) decreased significantly, these three materials will continue to be the most critical ones in the most impactful stage for each system analysed. Therefore, the conclusions on the most critical inputs for each system are considered as reliable and companies should focus their attention on these three inputs.

### 3.2 Comparison of systems

This step aims to compare the three systems by analysing the results obtained through the SLCA application in the previous step. Table 5 represents the SS values obtained for each system.

Table 5: Social SS comparison between the three systems

| | System 1 | System 2 | System 3 |
|---|---|---|---|
| **Social SS (kPt)** | 18043.2 | 411.4 | 2019.6 |

From the results of Table 4, it is possible to conclude that System 2 has the better social performance (411.4 kPt) and System 1 has the worst performance (18043.2 kPt). Therefore, planting *Quercus suber* will be the best option since this system has the lowest SS for the same system boundary and functional unit considered. Notice that the differences between the SS of System 1 and both System 2 and 3 are very different since the quantities used to model the three systems in the software are also very different (2929.86kg of natural cork stoppers vs. 529840.41 kg of uncoated woodfree paper). Nevertheless, since the concept of sustainability comprises three different dimensions, the next section will assess the overall sustainability of these three systems.

### 3.3 Sustainability Assessment

Finally, this last step aims to assess the three systems in terms of their sustainability performance. Table 6 summarizes the main results from a social, economic and environmental assessment.

Table 6: Sustainability assessment for the three systems

| | System 1 | System 2 | System 3 |
|---|---|---|---|
| **NPV (euros)*** | 34213.1 | 353.1 | 6093.7 |
| **Social Impact (Pt/euro)** | 527.4 | 1164.9 | 331.4 |
| **Environmental Impact (Pt/euro)*** | 2.9 | 60.6 | 5.2 |
| **Sustainability Ratio** $(kPt/euro^2)$ | 1.5 | 70.6 | 1.7 |

* Retrieved from Santos et al. (2021).

From the values of Table 6, one can conclude that System 1 has the best overall sustainability performance since it has the lowest value of Sustainability Ratio *(1,5 $kPt/euro^2$)* calculated from Equation (1) identified in section 2 of this paper. On the other hand, System 2 has the worst performance, and its value is significantly higher than both System 1 and 3. Therefore, planting *Eucalyptus globulus* to produce uncoated woodfree paper is the best option considering the three sustainability dimensions (social, economic, and environmental).

## 4. CONCLUSIONS

The application of the SLCA methodology to the three systems allowed to conclude that planting *Quercus suber* to manufacture natural cork stoppers is the best option from a social perspective, since this system has the least Social SS, considering the functional unit selected. However, since the concept of sustainability comprises three dimensions, conclusions about the other two pillars had to be made. From the combination of the Environmental SS, Social SS and NPV, it was possible to conclude that planting *Eucalyptus globulus* to produce uncoated woodfree paper is the best option from an overall sustainability performance. Besides these conclusions, the Health & Safety category was identified as the most critical for the forest sector, and the three main areas of concern in this sector are: IF, OTH and C. In this sense, when reporting social impacts, companies and other stakeholders should focus their attention on these impact subcategories.

Lastly, future work should be based on the development of a standardize methodology to quantify the social impacts of products and services, in order to have coherence between case studies. Regarding the SHDB, 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 (4) separate countries into different regions.

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