Environmental and Social Impacts of Cork Products and Forest Bioenergy

Corticeira Amorim and Omnipellets Case Study

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Abstract

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

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

Thus, the present study aims to assess the two least studied pillars of sustainability (environmental and social), applied to forest-based products from Portuguese companies (natural cork stoppers (NCS) and pellets) using the Environmental and Social Life Cycle Assessment methodologies (E-LCA and S-LCA). E-LCA and S-LCA are techniques that can be used to evaluate, respectively, the environmental and social impacts of a product's life cycle. According to the results obtained, the life cycle of NCS has fewer environmental and social impacts than the pellets life cycle. The most critical environmental issues for the forest sector are marine and terrestrial ecotoxicity, and human carcinogenic toxicity. The most critical social issues for this sector are the Injuries & Fatalities, the Occupational Toxics & Hazards, and the Corruption.

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

1. INTRODUCTION

The first appearance of the sustainability concept dates the year 1713. The city of Saxony, in Germany, was having a crisis of timber scarcity. The livelihood of a large part of this population was dependent on the mining industry, and this industry was consuming whole forests. Trees had been cut and not replaced for decades, which culminated in this scarcity timber crisis. In this sequence, the idea of sustainability was first introduced by Hans Carl von Carlowitz, a German tax accountant and mining administrator, in his book *Sylvicultura oeconomica* (von Carlowitz, 1713). Since then, the concept of sustainability has evolved and has been a matter of study. In 1987, sustainable development was defined as the "*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*." (World Commission on Environment and Development, 1987). Sustainability relies on three different pillars: economic, environmental, and social. The first one is the most measurable and objective. The other two dimensions are harder to quantify. However, the three dimensions are equally important. A study performed by Santos, Carvalho, Barbosa-Póvoa, Marques, & Amorim (2019) showed that the economic pillar is the most explored one, following the environmental and lastly the social pillar. So, it is important to elaborate more studies about the least studies ones.

Forest have a vital role in today's World. For that reason, they are a relevant topic, mainly because of all the threats and challenges that they face in nowadays' reality. The Portuguese forest occupies 3.2 million hectares which correspond to 35,4% of the Portuguese land. Portugal's economy strongly relies on forest activities, and they have a substantial impact on the Portuguese GDP (gross domestic product) – around 4,7% of the national GDP. Forest-based products (such as paper, board, pulp, cork, wood, resin products, and furniture) represent 10% of the total national exportations and 3% of GVA (gross value added) (PEFC Portugal, 2017). In terms of social benefits, the Portuguese forest also plays a fundamental role when it comes to providing livelihoods. This economic sector generates about 113 thousand direct jobs (around 2% of the active population) (PEFC Portugal, 2017). The combination of all these factors and numbers explains why the forest sector is relevant in Portugal and should be the object of study.

So, as already mentioned, the environmental and social pillars are the least explored ones and for this reason will be the ones analysed in this study. This study's goal is to apply the E-LCA and S-LCA methodologies to two forest products.

2. LITERATURE REVIEW

2.1 Environmental Life Cycle Assessment

Environmental Life Cycle Assessment (E-LCA) is a useful tool to evaluate the environmental impacts of a product/process/service throughout its life cycle (Demertzi, Dias, Matos, & Arroja, 2015). According to ISO 14040 and ISO 14044 (ISO, 2006a, 2006b), an E-LCA consists of four steps:

1. Goal and scope definition – this stage includes the explanation of the reason for executing the E-LCA, the clarification of the product/service (and the corresponding functional unit (FU)), the definition of the life cycle and the presentation of the system's boundary (PRé Consultants, 2019).

2. Inventory analysis – also known as Life Cycle Inventory (LCI), this step is focused on the identification of raw materials necessary in the production stage, water, energy usage and emissions that occur during life cycle, according to the FU (Demertzi, Dias, et al., 2015). There are some databases that have the information needed, such as the Econinvent, USDA, and the ELCD.

3. Impact assessment – it can also be called Life Cycle Impact Assessment (LCIA) and here, the data gathered in the previous step is converted into potential environmental impacts (Demertzi, Dias, et al., 2015). In this step, there are several methods that can be used, like ReCiPe, CML, IMPACT, TRACI, among others. Also, there are some software that help assess E-LCAs, such as SimaPro, GaBi, and OpenLCA.

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

3.1 Selection and identification of impact categories – selection and definition of the relevant environmental impact categories;

3.2 Classification – assigning the LCI results to the impact categories;

3.3 Characterization – Equation 1 shows how to calculate the characterized value:

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

S_j = Characterized indicator of the impact category j;

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

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

Besides these three steps, there are more three optional ones:

3.4 Normalization – to enable the comparison between impact categories, the characterized indicator is adjusted to a common reference. Equation 2 shows the calculations to get to the normalized value:

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

N_j = Normalized indicator of impact category j;

S_j = Characterized indicator of impact category j;

R_j = Reference value of impact category j;

3.5 Grouping – this stage is only performed when using the endpoint approach. Here, the impact categories are assigned to endpoint categories;

3.6 Weighting – the purpose here is to give different weights to the endpoint categories, to reflect their relative importance. After deciding the individual weight of each impact category, one will multiply these weights by their normalized value (Equation 3). By adding the weighted indexes of all impact categories, the single score is calculated(Equation 4).

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

Ω_j = Weight of impact category j

N_j = Normalized indicator of impact category j

W_j = Weighted index of impact category j

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

SS = Single score

W_j = Weighted index of impact category j

4. Interpretation – the results obtained in Steps 2 and 3 are evaluated and validated. The conclusions taken here should be aligned with the goal and scope of the E-LCA. This includes the identification of the steps/entities of the life cycle responsible for the majority of the environmental impacts, as well as the environmental issues most likely to emerge.

2.2 Social Life Cycle Assessment

UNEP/SETAC guidelines give directions and guidance on how to apply social life cycle assessment (S-LCA). According to these guidelines, S-LCA's methodology consists of four main steps (Russo Garrido, 2017):

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

2. Inventory analysis – or life cycle inventory analysis (LCI). Here, the social data is collected and organized. This data is typically gathered through questionnaires, literature review, existing instruments and/or databases (such as the SHDB or PSILCA);

3. Impact assessment – or life cycle impact assessment (LCIA). This stage can be subdivided into three sub-steps (Benoit-Norris et al., 2013):

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

3.2 Classification - linking inventory data to an impact category;

3.3 Characterization – determine the relative weight that each inventory item has in the impact category; calculate the result of the impact categories indicator (aggregating the weighted values – the value of the inventory item multiplied by its weight);

4. Interpretation – the results obtained in Steps 2 and 3 are evaluated and validated. The conclusions taken here should be aligned with the goal and scope of the S-LCA. This includes the identification of the steps/entities of the life cycle responsible for the majority of the social impacts, as well as the social issues most likely to emerge.

3. METHODOLOGY

Step 1 - E-LCA application

The first step is the E-LCA application to the case studies. As explained in Section 2.1, the E-LCA methodology consists of four main steps:

Step 1.1 – Goal and scope definition for the E-LCA studies

The first step of the E-LCA methodology is to define the goal and scope of the E-LCA studies. The full explanation was held in Section 2.1. The output of this step is the goal and scope of the E-LCA studies.

Step 1.2 – Inventory analysis (LCI) of the E-LCA studies

Step 1.2 aims to gather the inventory data needed to proceed with the E-LCA assessments. The output of this step is an inventory list with all the inputs and outputs (materials, water, energy, and emissions) throughout the systems' life cycle.

Step 1.3 – Impact assessment (LCIA) of the E-LCA studies

Step 1.3 starts with the decision of the LCIA method and software (Section 2.1 gives several options of methods and software). Then, the course of action is to insert the inventory list in the software and to select the desired LCIA method, and then let the software perform the calculations. So, the two main outputs of this step are the single score and the impact and damage categories (and respective values).

Step 1.4 – Interpretation of the E-LCA results

The results of Step 1.3 are analysed in this step. A common characteristic of all the results is that the higher their value, the worse its environmental "degree". Some analysis that will be performed are: the critical impact categories, the critical life cycle processes, the environmental hotspots and the recommendations.

Step 2 – S-LCA application

The social LCA consists of four main steps:

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

This step, parallelly to E-LCA's first step, also aims to clarify the reasons for doing this study (goal definition) and to define the scope of the study, which include the functional unit, activity variable, life cycle and boundaries.

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

This step intends to collect and organize the social data required for the following steps. Here, it is required to identify the prices (in USD of the year 2011) of the processes' inputs (materials/energy/water) as well as their country of origin and GTAP sector. So, the output of this step is an inventory list with the prices of the life cycle's inputs, their countries of origin and GTAP sector.

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

The input of this step is precisely the output of Step 2.2 – the inventory list. That data is analysed and assessed in potential social impact categories. For the data conversion into social impact categories, the use of a software is beneficial. Likewise Step 1.3 of this methodology, the course of action of this step is to insert the inventory list (output of Step 2.2) in the software and to select the desired LCIA method, and then let the software perform the calculations inherent to this step.

Step 2.4 – Interpretation of the S-LCA results

This is the last step in the S-LCA methodology: the interpretation of the results obtained in Step 2.3. The understanding of the outputs will be performed through several different analysis such as the critical impact categories, the critical life cycle processes, the social hotspots and the recommendations.

Step 3 – Comparison of systems

This step aims to take a wider look at the results of Steps 1 and 2, to compare the systems and to draw conclusions about the forest sector. The analysis performed in this step are the environmental and social comparisons in terms of impact categories, endpoint categories and single score results.

4. METHODOLOGY APPLICATION

4.1 Corticeira Amorim

4.1.1 Step 1 – E-LCA application

4.1.1.1 Step 1.1 – Goal and scope definition

The product under analysis is the natural cork stopper (NCS) produced by Corticeira Amorim. The goal and scope of this study are:

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

Scope:

Product characteristics (APCOR, 2015; Demertzi *et al.*, 2016): Product: natural cork stoppers (NCS); Shape: cylindric; Length: (45 ± 1) mm; Diameter: (24 ±0,5) mm; Density: 120-220 kg/m^3; Moisture: 4%-8%.

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

Boundaries: The system boundary is cradle-to-usage (Figure 1); the time boundary is one year; and the geographical boundary is the whole World (since the NCS life cycle is worldwide).

Life cycle: The life cycle of the natural cork stoppers is represented in Figure 1.

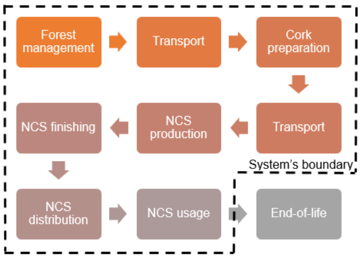

Figure 1 - NCS life cycle

The life cycle described in the present section is similar to the one presented by Demertzi, Silva, et al. (2016) and APCOR (2015). The first process of natural cork stoppers' life cycle is the **forest management**. This process includes the stand establishment, stand management, cork stripping and the field recovery. The forest management process takes place in Portugal, Spain, Morocco, Algeria and Tunisia. Then, the next process is the **transportation** of the raw cork to the cork preparation units where the **cork preparation** process takes place. This process includes: the planks pile establishment, the first stabilization, boiling, second stabilization, scalding and manual selection. The cork preparation locations are the same as the forest management ones. Once the cork planks are ready to be processed, they are **transported** to the production and finishing units (in Portugal). There it starts the **production** process, which includes slicing, punching, pre-drying, correction, aspiration, selection, washing, drying, deodorization, coloring and packaging. The next process in the life cycle of the natural cork stoppers is the **finishing**. This process includes five operations: dusting, branding, printing, surface treatment and packaging. The next process included in the system's boundary is the NCS **distribution**. The locations to where the NCS are transported to are: Portugal, France, Spain, Italy, Germany, USA, Australia, South Africa, Chile, Argentina, China, Bulgaria, Hungary, Moldavia and Austria. The last process contained within the system boundary is the NCS **usage**. The use of NCS does not have any environmental impact associated with it. The last process of the life cycle is the **end-of-life**, which is not included in the chosen boundary.

4.1.1.2 Step 1.2 - Inventory analysis (LCI)

Table 1 presents, as an example, the inventory list of the cork preparation process.

Table 1 - Inventory data per functional unit (cork preparation) (E-LCA) (Demertzi et al. (2016))

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

Table 1 - Inventory data per functional unit (cork preparation) (E-LCA) (Continuation)

4.1.1.3 Step 1.3 – Impact assessment (LCIA)

This step was performed using the SimaPro software and the method used was the ReCiPe 2016 (Hierarchist). The SimaPro is the chosen software since it is the most used one. ReCiPe is the chosen method because it is also one of the most used methods in the literature analysed and it is recommended by the United Nations (Santos *et al.*, 2019). The 17 midpoint categories of ReCiPe are: global warming (GW), stratospheric ozone depletion (SOD), ionizing radiation (IR), ozone formation (OF), fine particulate matter formation (FPMF), human carcinogenic toxicity (HCT), human non-carcinogenic toxicity (HNCT), water consumption (WC), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TEco), freshwater ecotoxicity (FEco), marine ecotoxicity (MEco), land use (LU), mineral resources scarcity (MRS), fossil resources scarcity (FRS). ReCiPe's three endpoint categories are: human health (HH), ecosystems (ECO) and resources (R).

4.1.1.4 Step 1.4 – Interpretation

The first analysis performed is to find the most impactful categories, and an efficient way to discover them is by applying the Pareto Rule to the normalized values of the midpoint categories. Figure 2 presents the application of the Pareto analysis.

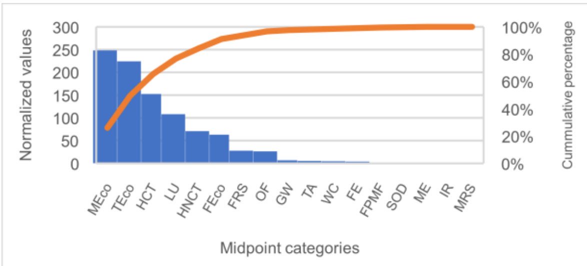

Figure 2 - Pareto analysis – NCS (E-LCA)

According to Figure 2, four categories (MEco, TEco, HCT and LU) are responsible for about 80% of the total environmental impacts.

Taking a closer look to these four categories, Figure 3 shows the contribution of each process to the most impactful categories.

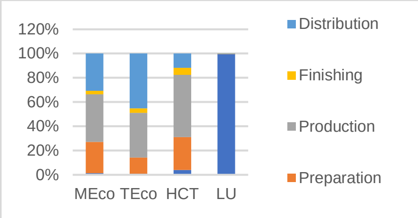

Figure 3 - Contribution of each process to the characterized values of the most relevant categories – NCS (E-LCA)

The process that contributes the most to the **marine ecotoxicity** is production (39%), followed by distribution (31%) and preparation (26%). When looking in more detail to the first mentioned process, one finds out that the biggest contributor to this process is the truck transportation (ROW) (38%). An alternative to the truck transportation is the train. A comparative analysis in SimaPro proved that the train transportation is less harmful to the environment than the truck, including in the MEco category. If Corticeira Amorim switched the transport mode to train, in the production stage (only in the Spain part – Scenario 1), the MEco characterized value decreases 7%. If the company opts for also using train transportation in Africa (Scenario 2), this provides a decrease of 10% in MEco's value. Then, the second input contributing the most to the production score is the natural gas (29%). Some alternatives to this input could be the solar energy or the wind energy. When comparing 1kWh of these three types of energy in SimaPro, the wind energy proves to be the best (in the MEco category). So, when implementing the wind energy in the production process instead of natural gas, the MEco value decreases 11%.

Moving on to the **terrestrial ecotoxicity** category, the process impacting the most this category is the distribution (45%) followed by production (37%), and preparation (13%).The majority of the distribution process impacts come from the truck transportation in Europe (62%). Then, the second input that contributes the most to the distribution process impacts is the truck transportation in the rest of the World (38%). So, in order to reduce the impacts of the TEco category, the most efficient way is by using alternatives to the truck transportation. Here, once again, the alternative lies on toggling between the truck and train modes. So, out of the 15 distribution locations, it was considered the most relevant ones in terms of quantity distributed and distance travelled, which are: France, Spain, Italy and Germany. So, after implementing the alterations, one can conclude that the option with train reduces the TEco impacts in about 20%.

The third most relevant category is the **human carcinogenic toxicity** (Figure 2). Figure 3 shows that the one process that impacts the most this category is the production process (51%), followed by preparation (27%), and distribution (12%). So, if the goal is to reduce the HCT impacts, it is important to look to the process that has the biggest impact – the production process. Inside this process, the input that has the highest contribution is the hydrogen peroxide (44%). The H_2O_2 is part of the washing procedure and it is required to disinfect the NCSs. Demertzi, Silva, et al. (2016) explains that this chemical cannot be altered because they are required in specific amounts in order to ensure the quality of the NCSs. The second most impactful element is the cork waste (28%). As previously mentioned, the best solution is to reintroduce it in the production of other products.

The only process contributing to the **land use** category is the forest management. The biggest contribution to this process in the LU category is the raw cork.

4.1.2 Step 2 - S-LCA application

4.1.2.1 Step 2.1 - Goal and scope definition

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

Scope:

The FU, boundary and life cycle are the same as the ones in Section 4.1.1.1.

4.1.2.2 Step 2.2 – Inventory analysis (LCI)

Table 2 shows, as an example, the inventory list of the cork preparation process of the NCS life cycle.

Table 2 - LCI of the cork preparation stage in Portugal, for Corticeira Amorim

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

4.1.2.3 Step 2.3 – Impact assessment (LCIA)

The software chosen is SimaPro. The method selected is Social Hotspot 2019 Subcategories & Categories Method with Damages. This method has five endpoint categories: Labour Rights & Decent Work (LRDW), Health & Safety (HS), Human Rights (HR), Governance (G) and Community (Cm). The midpoint categories belonging to the **LRDC** category are: Wage (W), Poverty (P), Child Labour (CL), Forced Labour (FL), Excessive Working Time (EWT), Freedom of Association, Collective Bargaining, and Right to Strike (FoA), Migrant Labour (ML), Social Benefits (SB), Labour Laws & Conventions (LLC), Discrimination (D) and Unemployment (U). Then, the impact categories of **HS** are: Occupational Toxics & Hazards (OTH) and Injuries & Fatalities (IF). The **HR** category divides into: Indigenous Rights (IRi), Gender Equity (GE), High Conflict Zones (HCZ), Non-Communicable Diseases and other health risks (NCD) and Communicable Diseases (CD). **G** category has two themes: Legal System (LS) and Corruption (Cr). Lastly, the themes of **C**: Access to Drinking Water (ADW), Access to Sanitation (AS), Children out of School (CoS) Access to Hospital Beds (AHB) and Smallholder vs. Commercial Farms (SCF).

4.1.2.4 Step 2.4 – Interpretation

Figure 4 shows the Pareto analysis to the impact categories.

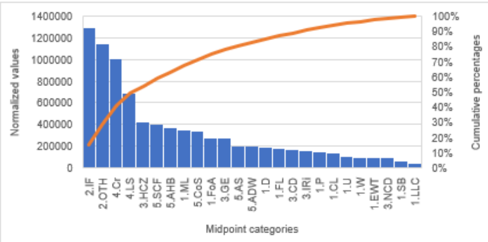

Figure 4 - Pareto analysis (midpoint categories) – NCS (S-LCA)

From Figure 4 it is possible to conclude that the categories responsible for 80% of the social impacts are: IF, OTH, Cr, LS, HCZ, SCF, AHB, ML, CoS, FoA, GE, and AS.

Figure 5 shows the contribution of each process of the NCS life cycle to these critical categories.

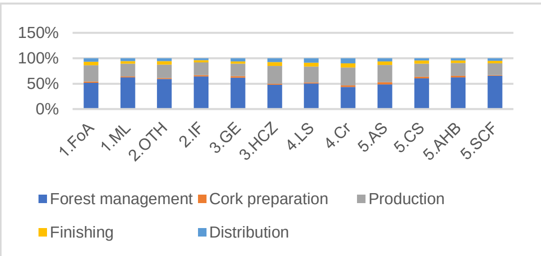

Figure 5 - Contribution of each process to the characterized values of the most relevant categories – NCS (S-LCA)

The most impactful category is the **IF** (see Figure 4). Around 64% of this category's impacts are from forest management, followed by production (25%), finishing (5%), distribution (5%), and preparation (2%). Around 68% of the forest management impacts in the IF category correspond to the forest management performed in Portugal. Then, 26% of these impacts are related to the Spanish forests, then Algeria (5%), Tunisia (2%) and Morocco (0%). Since the IF is the major social concern of the present life cycle and the forest management process in Portugal is the biggest contributor to this impact, then it would be valuable to reinforce the safety measures in the cork oak forests in Portugal.

Secondly, the **OTH** category comes next in the ranking. The trend in this category is similar to the one of the previous category. The process impacting the most this category is forest management with 59% of the overall impacts, followed by production (27%), finishing (7%), distribution (6%), and lastly the cork preparation (2%). Looking in detail to the forest management process, around 63% of the process impacts belong to the forest management in Portugal. Then, 20% correspond to the Spanish forest management. In the third position comes the Moroccan forests (14%), then Algeria and Tunisia with 2% and 1%, respectively. The value belonging to the forest management process in Morocco can be considered high when comparing relatively with the amount of cork the first two locations are dealing with. So, this high value of the forest management process in Morocco alerts for possible problems in this country, which require surveillance.

4.2 Omnipellets

4.2.1 Step 1 – E-LCA application

4.2.1.1 Step 1.1 – Goal and scope definition

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

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

Scope:

Product characteristics (Ferreira, Fernandes and Nunes, 2015; Omnipellets, 2020): Product: Pellets; Shape: cylindric; Diameter: 6 mm; Length: 3,15 to 40 mm; Density: 600-750 kg/m^3; Moisture: 10%.

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

Boundaries: The system's boundary is cradle-to-usage (Figure 6); the time boundary is one year; and the geographical boundary is Portugal.

Life cycle: Figure 6 illustrates the product's life cycle.

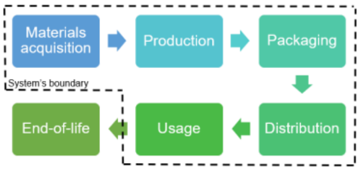

Figure 6 - Pellets life cycle

The life cycle processes described is similar to the ones studied by Quinteiro et al. (2019) and Ferreira et al. (2015). The information in the company's Webpage (Martos & Cª Lda., 2018b) was also useful.

The first process in the pellet's life cycle is the **materials** (sawdust and wood chips) **acquisition**. These materials are by-products created during the production of pallets. These materials are already inside the industrial unit, because the Omnipellets facility is in the same location as the Martos' pallet production facility (Martos group produces the pallets). So, they do not need to be transported. This process (material acquisition) does not have any environmental. This process takes place in Omnipellets' facilities in Leiria, Portugal. The next process is the **production**. This step includes the separation, trituration, drying, refining and compression.

The next process is **packaging**. The product is put together in (LDPE) bags containing 15kg of pellets. After having the product properly packed, they are ready to be **distributed**. The pellets are distributed to several location inside Portugal. In order to simplify, three distinct locations were chosen: Bragança, Castelo Branco and Faro. The last process included in the system's boundary is denominated **usage**. The pellets are going to be combusted because their purpose is to give energy (heat). The actual last process of pellet's life cycle is the end-of-life, which is not included in the system's boundary.

4.2.1.2 Step 1.2 – Inventory analysis (LCI)

Table 3 shows, as an example, the inventory list of the pellet production process.

Table 3 - Inventory data per functional unit (pellet production)

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

4.2.1.3 Step 1.3 – Impact assessment (LCIA)

The software and methods, as well as the midpoint categories chosen were all presented in Section 4.1.1.3.

4.2.1.4 Step 1.4 – Interpretation

In order to understand which are the most worrying midpoint categories, one needs to look to its normalized values to be able to compare them. Figure 7 shows the Pareto analysis.

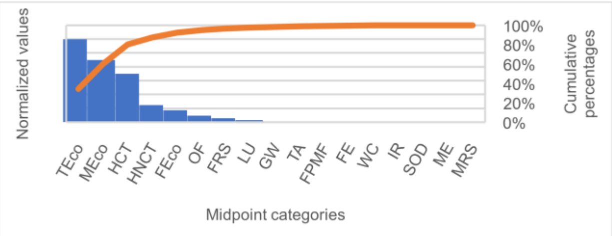

Figure 7 - Pareto analysis (midpoint categories) using ReCiPe – Pellets (E-LCA)

As one can observe in Figure 7, the first three categories (TEco, MEco and HCT) correspond to 80% of the total environmental impacts.

Figure 8 shows the contribution of each process to these three most impactful categories.

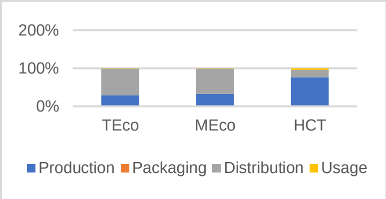

Figure 8 - Contribution of each process to the characterized values of the most relevant categories – Pellets (E-LCA)

So, starting this analysis with the **terrestrial ecotoxicity** category, as one can observe in Figure 8, the most relevant process is the distribution (70%), followed by production (29%), usage (1%), and packaging (0%). The distribution stage impacts are entirely coming from the truck transportation. The alternative is to combine the truck and train transportation. Since the railway to Castelo Branco is complex, two alternative scenarios are tested: one with using train in all three destinations (Bragança, Castelo Branco and Faro) (Scenario 1), and other that just uses train to Bragança and to Faro (Scenario 2). So, the first scenario provides a decrease of around 52% of the TEco value, while the second scenario just decreases the TEco category in about 42%. However, it is important to keep in mind that even if the second scenario has a smaller decrease, it still brings a big decrease and it is a more feasible scenario.

Then, the next category under analysis is the **marine ecotoxicity**. Also in this category, the process accountable for the majority of the impacts is the distribution (66%), followed by production (33%), usage (1%), and lastly the packaging (around 0%). Once again, the distribution process impacts are assigned to the truck transportation. So, the two alternative scenario previously mentioned are also valid for the present case. When it comes to the MEco category, these two scenario have a strong impact. Scenario 1 provides a decrease of 47%, and the Scenario 2 a decrease of 38%.

The third and last category under analysis in this part is the **human carcinogenic toxicity**. Here, the process responsible for the majority of the impacts is production (76%), followed by distribution (19%), and usage (4%). Once again, the packaging process does not have any HCT impacts. Around 89% of the production impacts correspond to the wood chips. So, in order to decrease the HCT impacts, it would be valuable to decrease the amount of woodchips used in the process. Scenario 80% analyses a decrease of 20% in the amount of wood chips used and Scenario 90% a decrease of 10%. In the HCT category, the Scenario 80% provides a 18% decrease of the production impacts, while the Scenario 90% allows a decrease of 9%.

4.2.2 Step 2 – S-LCA application

4.2.2.1 Step 2.1 – Goal and scope definition

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

Scope:

The scope is the same as described in Section 4.2.1.1.

4.2.2.2 Step 2.2 – Inventory analysis (LCI)

Table 4 shows the inventory list for the pellet production stage, as an example.

Table 4 - LCI of the pellet production stage in Portugal, for Omnipellets

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

4.2.2.3 Step 2.3 – Impact assessment (LCIA)

The method and software is the same as used in Section 4.1.2.3.

4.2.2.4 Step 2.4 – Interpretation

Figure 9 shows the Pareto analysis applied to the normalized values of the midpoint categories.

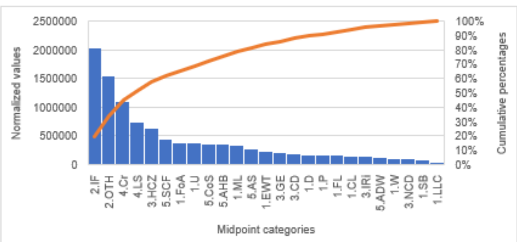

Figure 9 - Pareto analysis (midpoint categories) – Pellets (S-LCA)

According to Figure 9, the most impactful categories are, in order: IF, OTH, Cr, LS, HCZ, SCF, FoA, U, CoS, AHB and ML. Figure 10 shows the contribution of the life cycle processes to the most relevant categories.

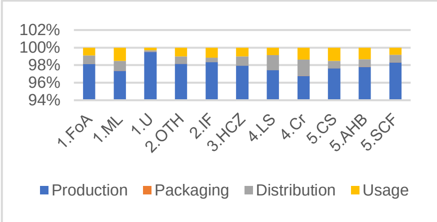

Figure 10 - Contribution of each process to the characterized values of the most relevant categories – Pellets (S-LCA)

According to Figure 9, the most impactful category is the **Injuries & Fatalities** (IF). As one can observe in Figure 10, the biggest process impacting the most this category is the production (around 98%)., then the distribution and usage, with 1% each. The input of the production process that impacts the most this category is the wood chips from Spain (51%), then the wood chips from Portugal (45%) and lastly the sawdust and electricity from Portugal (both with 2%). The recommendation here is to analyse the wood chips industry in both Portugal and Spain in order to find safety measures to reduce the injuries and fatalities rates. The measures can be related with the workers uniforms, safety wearing, machinery, etc.

The second most worrying midpoint category is the **Occupational Toxics & Hazards** (OTH) (see Figure 9). According to Figure 10, this category follows the same trend set by the IF category. The production process gathers around 98% of the impacts, then the distribution and usage have both an impact of 1%. Looking in more detail to the production process, the input that is the most relevant one is the wood chips from Spain (63%). The second most impactful input of the production process is the wood chips from Portugal (33%). So, regarding the OTH, the Spanish wood chips gains more relevance than in the injuries and fatalities category, when comparing to the Portuguese wood chips. The suggestion to reduce the impacts of this category is once more to look to the wood chips industry and to analyse the chemicals used that might be causing health problems to the workers.

4.3 Step 3 – Comparison of systems

One starts this analysis with the **environmental comparison**. Regarding the midpoint values, the pellets life cycle has worse performance in almost all of the impact categories. The exceptions are the SOD, the ME and the LU, where the NCS life cycle presents a higher value. So, according to the midpoint categories, one can affirm that we are facing a trade-off. For that reason, one cannot formulate a conclusion about which life cycle is environmentally better. However, when performing the Pareto analysis to the normalized values of both life cycle, one found that the most relevant categories in the NCS case are the MEco, TEco, HCT and LU, by order; and in the pellets case are the TEco, MEco and the HCT, by order. So, it is possible to conclude that these two systems have three categories in common as the most worrying ones. Therefore, this indicates that these three environmental issues are, possibly, matters of concern to the forest sector. Also, when a closer analysis to this categories was performed, it was concluded that the most impactful processes of the two life cycles are the production and distribution. In both cases, the distribution process (when on land) was being performed only by truck, and the possibility of using truck combined with train was studied and proved to be better. Regarding the production process, the biggest issues were related with the amount of raw materials used (cork and wood chips) and with the sources of energy. The suggestions to improve this process were to reduce the amount of raw materials used in the process and to change the energy source to either wind or solar. So, the recommendations given to the forest sector, are to analyse the possible routes with the train, to switch to either wind or solar energy and lastly, to study the optimization of the raw materials use. Since the midpoint categories did not allow a conclusion regarding which life cycle has a better environmental performance, one moves on to the endpoint level. Figure 11 shows the three endpoint categories and enables the comparison between systems.

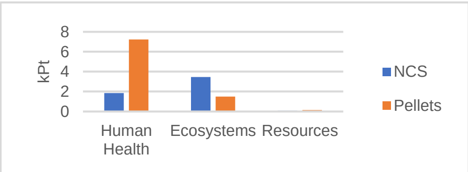

Figure 11 - Comparison of the endpoint categories - E-LCA

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

Since the endpoint categories also show a trade-off, one moves to the last possible indicator – the single score. Figure 12 shows the values of the single scores of the two cases studies.

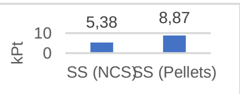

Figure 12 - SS (E-LCA) comparison

Figure 12 illustrates that the pellets' single score (8,87 kPt) is higher than the NCS's SS (5,38 kPt), which means that, overall, the pellets life cycle has a higher environmental impact than the NCS life cycle, for the same system boundary and functional unit.

Then, one moves on to the **social comparison**. The majority of the impact categories have a higher (characterized) value in the pellets' life cycle than in the NCS. However, there are some exceptions. The exceptions are: CL, FL, ML, D, IR, GE, ADW and AHB. So, this is again a trade-off situation. For that reason, the next parameter to be analysed are the endpoint categories. But firstly, an overview to the forest sector is performed. Between the most relevant categories of these two systems, the ones that are common are: FoA, ML, OTH, IF, HCZ, LS, Cr, CS, AHB and SC, so, these are considered to be the biggest social issues of the forest sector. Regarding the life cycle processes, it was proved that the most worrying ones to the NCS case are the forest management and the production, and in the pellets life cycle is the production. Since the common point is the production point, that is the one considered to be the most worrying and the one to be watched in the forest sector. Besides that, the countries that had more impact in the systems life cycle were Portugal and Spain (and also Morocco in the NCS case). So, the main recommendations are to reinforce the security in the job with more protection and close attention to the safety of the workers. Moving on to the next analysis, Figure 13 shows the comparison of the endpoint categories between the two systems under study.

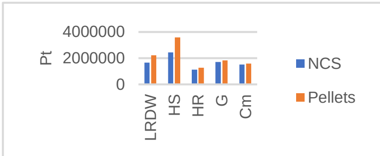

Figure 13 - Comparison of the endpoint categories - S-LCA

The pellets' life cycle has a higher value in all categories, which means that the pellets have a worse social performance than the NCS. The ranking order of the endpoint categories is almost the same, the only changes are in the LRDW category and in the G. The LRDW category occupies the second place in the pellet's case and the third in the NCS's one, while the latter one is the opposite. So, this means that the forest sector has its biggest social issues in the HS category, then in the LRDW and in the G. These three categories are the most worrying social issues to this sector. Moving to the last indicator, Figure 14 shows the social single scores of NCS and pellets life cycles and it enables the comparison between the two.

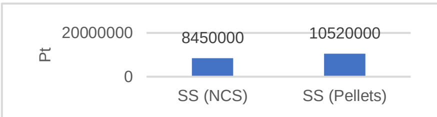

Figure 14 - SS (S-LCA) comparison

So, according to Figure 14, the pellets life cycle has a higher SS than the NCS, which indicates that the pellets have a worse social performance.

5. CONCLUSIONS

The application of the two methodologies (E-LCA and S-LCA) to the case studies (NCS by Corticeira Amorim and pellets by Omnipellets) allowed to conclude that, to generate a revenue of 100.000€, the pellet production is worse than the NCS production, both in social and environmental terms. Besides that, the analysis performed allowed to identify some similarities between the case studies. In a broad way, regarding the environmental field, the major key issues of the forest sector are the human health and the ecosystems. If one analyses the midpoint level, the environmental problems are similar in both CSs. The MEco, TEco and HCT categories, even though in a different order, are common to the two case studies, which indicates that the forest sector may find environmental issues in these three categories. When moving on to the social department, the identified social areas of concern in the forest sector are: FoA, ML, U, OTH, IF, HCZ, LS, Cr, CS, AHB, SCF, GE and AS; which converted into endpoint indicators show that the most relevant categories are the HS, the LRDW and the G.

Lastly, regarding the future work, a suggestion is to try to develop a LCA methodology for the economic pillar of sustainability, in order to have the three LCAs for the three pillars. Besides that, it would be valuable to have more guidance and guidelines for the application of these methodologies, as well as conformity in the information and existing literature (especially to the S-LCA).

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