# Environmental evaluation of the cork sector in Southern Europe (Catalonia)

By

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<<Del suro i del porc, se n'aprofita tot>>

Frase tradicional catalana

The present thesis entitled *Environmental evaluation of the cork sector in Southern Europe (Catalonia)* has been carried out at the Institute of Environmental Science and Technology (ICTA) at Universitat Autònoma de Barcelona (UAB) under the supervision of Dr. Joan Rieradevall and Dr. Xavier Gabarrell, both from the ICTA and the Department of Chemical Engineering at the UAB.

Bellaterra (Cerdanyola del Vallès), July 2011

Xavier Gabarrell Durany　　　　　　　　　　Joan Rieradevall Pons

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| | |
|---|---|
| 1.4 DB eq. | 1.4 dichlorobenzene equivalent emissions |
| ADP | abiotic depletion potential |
| AECORK | Association of Cork Companies of Catalonia |
| AP | acidification potential |
| APCOR | Portuguese Cork Association |
| BAT | best available techniques |
| BUWAL | Swiss Agency for the Environment, Forests and Landscape |
| $C_2H_4$ eq. | ethylene equivalent emissions |
| CBA | cost-benefit analysis |
| CBH | circumference at breast height |
| CDTI | Centre for the Development of Industrial Technology |
| CED | cumulative energy demand |
| CFC | Catalan Association of Forest Owners |
| CFC11 eq. | trichlorofluoromethane equivalent emissions |
| CM | checklist method |
| CML | Institute of Environmental Sciences (Leiden) |
| $CO_2$ | carbon dioxide |
| $CO_2$ eq. | carbon dioxide equivalent emissions |
| COD | chemical oxygen demand |
| DC | debarking coefficient |
| DMC | direct material consumption |
| DMI | direct material input |
| EA | energy analysis |
| EF | ecological footprint |
| EIA | environmental impact assessment |
| EIP | eco-industrial park |
| ELCD | European Reference Life Cycle Database |
| EMPA | Swiss Federal Laboratories for Materials Testing and Research |
| EP | eutrophication potential |
| ERA | environmental risk assessment |
| FAETP | freshwater aquatic ecotoxicity potential |
| FSC | Forest Stewardship Council |
| FU | functional unit |
| GWP | global warming potential |
| HDPE | polyethylene |
| HNVF | High Nature Value Farmlands |
| HTP | human toxicity potential |

| | |
|---|---|
| ICSuro | Catalan Cork Institute |
| ICTA | Institute of Environmental Science and Technology |
| IE | industrial ecology |
| IKP | Institute for Polymer Testing and Polymer Science (University of Stuttgart) |
| ILCD | International Reference Life Cycle Data System |
| IOA | input-output analysis |
| ISO | International Standardisation Organisation |
| LCA | life cycle assessment |
| LCC | life cycle costing |
| LCCA | life cycle cost analysis |
| LCECA | life cycle environmental cost analysis |
| LCI | life cycle inventory |
| LCIA | life cycle impact assessment |
| LCWE | life cycle working environment |
| MAETP | marine aquatic ecotoxicity potential |
| MEFA | material and energy flow analysis |
| MFA | material flow accounting |
| MFCA | material flow cost accounting |
| MIPS | material intensity per unit service |
| ODP | ozone layer depletion potential |
| PEFC | Programme for the Endorsement of Forest Certification |
| $PO_4^{3-}$ eq. | phosphate equivalent emissions |
| POCP | photochemical ozone creation potential |
| RAD | radioactive radiation |
| Sb eq. | antimony equivalent emissions |
| SD | sustainable development |
| SEA | strategic environmental assessment |
| SEEA | system of economic and environmental accounts |
| SETAC | Society of Environmental Toxicology and Chemistry |
| SFA | substance flow analysis |
| SH | stripping height |
| SLCA | social life cycle assessment |
| $SO_2$ eq. | sulphur dioxide equivalent emissions |
| SosteniPrA | Sustainability and Environmental Prevention |
| TCA | trichloroanisoles |
| TETP | terrestric ecotoxicity potential |
| TMR | total material requirement |
| UAB | Universitat Autònoma de Barcelona |
| UNEP | United Nations Environment Programme |

# Acknowledgments

The authors would like to thank the ICSuro, AECORK, CFC, for their essential support. We would also like to thank the Spanish Ministry for Industry, Tourism and Trade for the financial support in the CENIT project DEMETER ("*Desarrollo de Estrategias y Métodos Vitícolas y Enológicos frente al Cambio Climático - SA 72*"), and the "*ECOTECH SUDOE, soe2/P2/E377: LCA and Ecodesign International Network for Environmental Innovation*" project.


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Des de l'octubre de 2007 he tingut la fortuna de fer recerca sobre la gestió de residus i sobre el sector surer a Catalunya des d'una perspectiva ambiental. Gràcies a aquests treballs he pogut compartir molts moments amb moltes persones de diferents àmbits que m'ha suposat un gran benefici acadèmic, professional i, sobretot, personal. Estic molt agraït a totes les persones que han contribuït de manera directa o indirecta tant en la tesi com en la meva formació. En especial, he d'agrair l'oportunitat que em van donar els meus directors de tesi, Joan Rieradevall i Xavier Gabarrell, per a desenvolupar aquesta recerca.

No voldria oblidar-me de tota la gent de l'Institut Català del Suro, que m'ha ajudat tant durant tot aquest temps, i molt especialment l'Ivan Fernández, que ha estat clau en el desenvolupament de la tesi i m'ha donat suport durant tot el projecte Cenit-Demeter. També vull esmentar totes les empreses que han participat activament en el projecte, a les finques forestals i al Consorci Forestal de Catalunya, sense els quals no hauria pogut aconseguir l'objectiu plantejat. Espero que la meva tesi sigui només el primer pas d'un llarg camí del sector surer cap a la sostenibilitat i el medi ambient.

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Finalment, voldria donar les gràcies a tots els companys i amics que m'han acompanyat durant tots aquests anys, i d'una manera molt especial vull agrair a la meva família, la peça transcendental de la meva vida, tot el seu suport incondicional en els bons i mals moments. A la meva mare, a les meves germanes, al meu cosí, a la meva tieta, als meus tiets i cunyats i, molt especialment, al meu Avi i la meva Iaia, que són els millors del món! També, al Francesc que ja fa molts anys que està al meu costat incondicionalment.

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# Summary

Cork is a natural, renewable material, and is typically Mediterranean in the sense that this area, in particular the Iberian Peninsula, is home to the majority of cork oak forests and, therefore, most cork extraction activity. Cork is used to make many products, but in Catalonia the industry of making closures for wine and *cava* bottles, which are products of high added value, is especially important. Worldwide, 10% of wine stoppers and 60% of *cava* stoppers are made in Catalonia.

The lack of environmental data for the cork sector, together with competition from new products made with non-renewable materials, like synthetic or aluminium stoppers, are among the main reasons why the sector has decided to move in the direction of sustainability.

Life Cycle Analysis (LCA) is a tool used to assess the environmental impacts of products and systems throughout their life. This tool, used widely in other industrial sectors, is applied for the first time to the Catalan cork sector in this thesis, by analysing the sector both globally and by subsystems. The weaknesses of the sector's various subsystems have been detected, and proposals made regarding measures to favour cleaner production methods and key strategies to reduce the environmental impacts of cork products. Furthermore, the integrated analysis of the sector can lead to establishing global strategies for improvement based on industrial ecology, which will allow the sector to continue its advance towards sustainability.

The results indicate that cork is a low-impact material that, as well as generating many products, contributes towards fixing Carbon dioxide. For every tonne of cork transformed into products 14.3 t of $CO_2$ are fixed, so it can be said that the cork sector plays its part in the fight against climate change.

This thesis is the first step towards sustainability taken by the sector, and it would be good to continue working along these lines, and also on other research that will be crucial in the future. Some of the areas that need investigation are: new potential cork products, with a greater added value, a pilot study of higher-impact operations, for which there could be various technological alternatives, and $CO_2$ fixation associated with cork oaks.

# Resum

El suro és un material natural, renovable i típicament Mediterrani, ja que la majoria de l'extracció de suro i, per tant, dels boscos d'alzina surera, se situa en aquesta àrea, i molt especialment a la península Ibèrica. El suro s'utilitza per a fabricar nombrosos productes, però a Catalunya destaca molt especialment la indústria de taps per a vins i caves, que són productes d'alt valor afegit. A escala mundial el 10 % dels taps de vi i el 60 % dels taps de cava són produïts a Catalunya.

La manca de dades ambientals del sector surer, juntament amb l'aparició de competidors amb nous productes fets amb materials no renovables com els taps sintètics o d'alumini, han estat algunes de les principals justificacions perquè el sector hagi decidit avançar cap a la sostenibilitat.

L'anàlisi de cicle de vida (ACV) és una eina utilitzada per a avaluar els impactes ambientals de productes i sistemes al llarg de la seva vida. Aquesta eina ambiental, que s'ha utilitzat àmpliament en altres sectors industrials, s'empra per primer cop en el sector surer a Catalunya en la present tesi, l'objectiu de la qual ha estat l'avaluació ambiental del sector surer mitjançant l'anàlisi del sector, tant globalment com també per subsistemes. S'han determinat els punts febles dels diferents subsistemes del sector, de manera que es proposen mesures de producció més netes com a estratègies clau per a disminuir els impactes ambientals associats a cadascun dels productes de suro. A més, l'anàlisi del sector integrat permet establir estratègies globals de millora del sector des d'una perspectiva de l'ecologia industrial que permetran que el sector continuï avançant cap a la sostenibilitat.

Els resultats indiquen que el suro és un material amb un impacte ambiental baix que, a més de generar nombrosos productes, contribueix a fixar diòxid de carboni. Concretament, per cada tona de suro transformat en productes es fixen 14.3 t de $CO_2$, i per tant es pot afirmar que el sector del suro contribueix en la lluita contra el canvi climàtic.

Aquesta tesi ha estat el primer pas del sector cap a la sostenibilitat i s'hauria de continuar treballant en aquesta línia, així com en altres investigacions que seran claus en el futur. Alguns dels aspectes que convé investigar són els potencials nous productes de suro, amb un valor afegit més alt, l'estudi pilot de les operacions més impactants per a les quals hi poden haver diferents alternatives tecnològiques i l'aprofundiment en el coneixement sobre la fixació de $CO_2$ associada a l'alzina surera.

# Resumen

El corcho es un material natural, renovable y típicamente Mediterráneo, ya que la mayoría de la extracción de corcho y, por lo tanto, de los bosques de alcornoque, se sitúa en esta área, y muy especialmente en la península Ibérica. El corcho se utiliza para fabricar numerosos productos, pero en Cataluña destaca muy especialmente la industria de tapones para vinos y cavas, que son productos de alto valor añadido. A escala mundial, el 10% de los tapones de vino y el 60% de los tapones de cava son producidos en Cataluña.

La falta de datos ambientales del sector corchero, junto con la aparición de competidores con nuevos productos fabricados con materiales no renovables, como los tapones sintéticos o de aluminio, han sido algunas de las principales justificaciones para que el sector haya decidido avanzar hacia la sostenibilidad.

El análisis de ciclo de vida (ACV) es una herramienta utilizada para evaluar los impactos ambientales de productos y sistemas a lo largo de su vida. Esta herramienta ambiental, que se ha utilizado sobradamente en otros sectores industriales, se utiliza por primera vez en el sector corchero en Cataluña en la presente tesis, el objetivo de la cual ha sido la evaluación ambiental del sector del corcho mediante el análisis del sector, tanto globalmente como también por subsistemas. Se han determinado los puntos débiles de los diferentes subsistemas del sector, de modo que se proponen medidas de producción más limpias como estrategias clave para disminuir los impactos ambientales asociados a cada uno de los productos de corcho. Además, el análisis del sector integrado permite establecer estrategias globales de mejora del sector desde una perspectiva de la ecología industrial que permitirán que el sector continúe avanzando hacia la sostenibilidad.

Los resultados indican que el corcho es un material con un impacto ambiental bajo que, además de generar numerosos productos, contribuye a fijar dióxido de carbono. Concretamente, por cada tonelada de corcho transformado en productos se fijan 14.3 t de $CO_2$, por lo que se puede afirmar que el sector del corcho contribuye en la lucha contra el cambio climático.

Esta tesis ha sido el primer paso del sector hacia la sostenibilidad y se tendría que continuar trabajando en esta línea, así como en otras investigaciones que serán claves en el futuro. Algunos de los aspectos que conviene investigar son los potenciales nuevos productos hechos de corcho, con un valor añadido más alto, el estudio piloto de las operaciones más impactantes para las que puede haber diferentes alternativas tecnológicas y la profundización en el conocimiento sobre la fijación de $CO_2$ asociada al alcornoque.

# Preface

This doctoral thesis was developed within the research group SosteniPrA (Sustainability and Environmental Prevention) at the Institute of Environmental Science and Technology (ICTA) of the Universitat Autònoma de Barcelona (UAB) from December 2008 to May 2011. Previously, from October 2007 to December 2008, a master research thesis about waste collection systems was also carried out in the SosteniPrA group in order to access doctorate studies.

This dissertation analyses the cork sector in Catalonia (Northern Spain) from an environmental perspective. The research attempts to highlight the environmental benefits of cork as a material; but goes further and seeks to quantify and analyze the environmental impacts associated with the material and its main products in Catalonia and to propose strategies to improve production from a sustainability point of view.

The doctoral thesis was based on the methodology and results developed during the following project:

- *Desarrollo de Estrategias y Métodos vitícolas y Enológicos frente al cambio climático. Aplicación de nuevas Tecnologías que mejoren la Eficiencia de los procesos Resultantes – Subproyecto SA 7.2: Evaluación ambiental del sector del vino mediante el análisis de ciclo de vida (ACV) del tapón de corcho y el tapón de cava.* 2008-2011. A project by Cenit-Demeter funded by the Centre for the Development of Industrial Technology (CDTI) part of the Ministry of Science and Innovation. The Project was coordinated by AECORK (the cork industry business association) and had the participation of the Catalan Cork Institute and was developed by the Universitat Autònoma de Barcelona (ICTA - Institute of Environmental Science and Technology).

The dissertation is mainly based on the following papers either published or under review in peer-reviewed indexed journals:

- Rives, J., Fernandez-Rodriguez, I., Rieradevall, J., Gabarrell, X. Environmental analysis of the production of natural cork stoppers in southern Europe (Catalonia - Spain). Journal of Cleaner Production, 2011. 19(2-3): p. 259-271.

- Rives, J., Gabarrell, X., Fernandez-Rodriguez, I., Rieradevall, J., Environmental analysis of cork granulates production in southern Europe (Catalonia - Spain). Submitted on January 2011 to *Resources, Conservation and Recycling.*

- Rives, J., Fernandez-Rodriguez, I., Rieradevall, J., Gabarrell, X. Environmental analysis of the production of champagne cork stoppers in southern Europe (Catalonia - Spain). Submitted on March 2011 to *Journal of Cleaner Production.*

- Rives, J., Fernandez-Rodriguez, I., Rieradevall, J., Gabarrell, X. Environmental analysis of the raw cork extraction in cork oak forests in Southern Europe (Catalonia – Spain). Submitted on May 2011 to *Journal of Environmental Management.*

- Rives, J., Fernandez-Rodriguez, I., Rieradevall, J., Gabarrell, X. Environmental analysis of the cork sector in Southern Europe (Catalonia – Spain) from an industrial ecology perspective. Submitted on June 2011 to *Environmental Science & Technology.*

Moreover, the following oral communications and posters presented to congresses and conferences also form part of this doctoral thesis:

- Rives J, Fernandez-Rodriguez I, Gabarrell X, Rieradevall J. Environmental evaluation by means of LCA of a renewable material product: the natural cork stopper. 2010. Oral communication. *International Conference on Ecobalance*. Tokyo (Japan).
- Rives J, Gabarrell X, Rieradevall J. 2010. Life cycle assessment of natural cork stoppers production in Catalonia. Oral communication. *II International Conference on Wine ecological, sustainable and climate change (Ecososteniblewine)*. Vilafranca del Penedès (Barcelona – Spain).
- Gabarrell X, Rives J, Fernandez-Rodriguez I, Rieradevall J. 2010. Life cycle assessment of the industrial production of natural cork stoppers for still wine Poster. *II International Conference on Wine ecological, sustainable and climate change (Ecososteniblewine)*. Vilafranca del Penedès (Barcelona – Spain).
- Rives J, Fernandez-Rodriguez I, Rieradevall J, Gabarrell X. Carbon footprint associated to the production of natural cork stoppers. 2011. Oral communication. *4th edition of the International Life Cycle Assessment Conference in Latin-America (CILCA).* Coatzoalcos (Mexico).
- Rives J, Fernandez-Rodriguez I, Rieradevall J, Gabarrell X. Environmental evaluation by means of LCA of champagne cork stopper production. 2011. Poster. *Life Cycle Management International Conference (LCM).* Berlin (Germany).

Apart from this, during the dissertation period the following paper in a peer-reviewed journal was published:

- Rives J, Rieradevall J, Gabarrell X. LCA comparison of container systems in municipal solid waste management. Waste Management, 2010. 30: p. 949-957.

# Structure of the dissertation

The structure of the dissertation is organised into five main parts and eight chapters. For clarity, the structure of the doctoral thesis is further outlined in Figure 0. This flow chart can be used throughout the reading of this manuscript as a *dissertation map*.

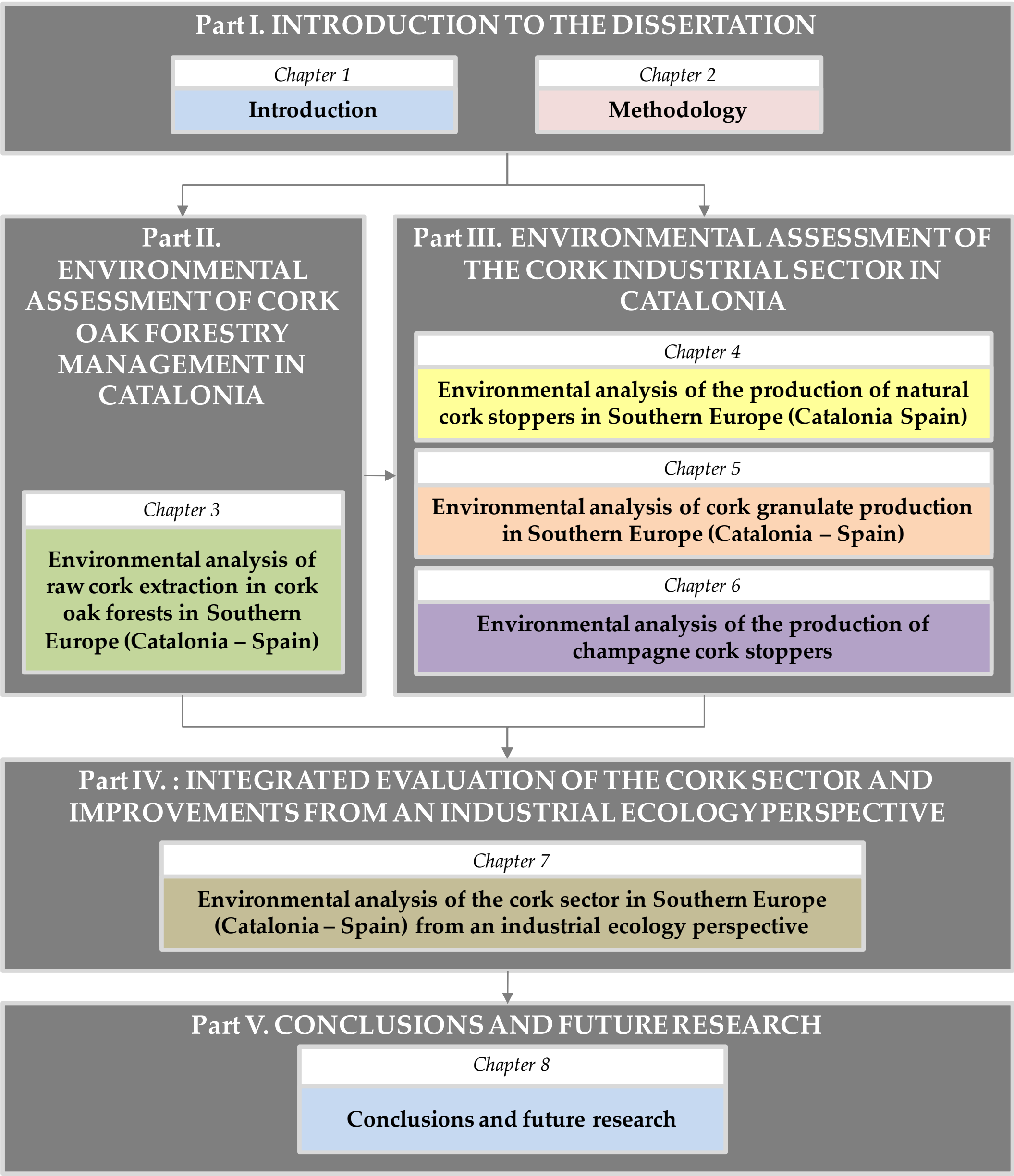



**Figure 0. Map structure of the dissertation.**

## *Part I. Introduction to dissertation*

**Part I** is composed of two chapters. **Chapter 1** contextualises cork as a natural, renewable and local raw material of Mediterranean areas, and Catalonia in particular. In addition, this chapter describes the cork sector divided into two sub-sectors: forestry and industry. This is because both will be assessed separately during the dissertation due to a difference in scope and approach. At the end of this chapter, the justification and objectives of this dissertation are explained. **Chapter 2** describes the methodology followed during the dissertation, especially the systems under study, the life cycle assessment (LCA) environmental tool, and the fieldwork carried out to characterise and collect data for the environmental assessment of the systems.

## *Part II. Environmental assessment of cork oak forestry management in Catalonia*

**Part II** is composed of **Chapter 3** [*Environmental analysis of the raw cork extraction in cork oak forests in Southern Europe (Catalonia – Spain)*]. This chapter first briefly introduces cork oak forests, and then the system under study and a description of the approach to the specific methodology employed. Following this we show the results of the environmental impacts associated to the management of cork oak forests to extract raw cork material and a carbon dioxide balance is performed. Finally, the conclusions of the chapter are presented.

## *Part III. Environmental assessment of the cork industrial sector in Catalonia*

**Part III** focuses on the environmental evaluation of three products made basically of cork. **Chapter 4** [*Environmental analysis of the production of natural cork stoppers in Southern Europe (Catalonia – Spain)*] presents the evaluation of a product composed completely by solid cork: the natural cork stopper for still wine. It quantifies the total potential environmental impacts caused during their production and assesses the stages and operations of the production that most contribute to these impacts. **Chapter 5** [*Environmental analysis of cork granulate production in Southern Europe (Catalonia – Spain)*] presents the environmental evaluation of an intermediate product: cork granulate. This intermediate product generated after certain processes of cork trituration and mixed with glues generates agglomerated cork products. There are two types of granulates: white cork granulate used mainly to produce technical stoppers for health and safety purposes, and the black cork granulate used for innumerable other applications. **Chapter 6** [*Environmental analysis of the production of champagne cork stoppers*] realises the evaluation of champagne cork stoppers production from an environmental perspective. This type of stopper is a combination of products analysed in chapter 4 and chapter 5, because it is formed by two natural cork discs made of solid cork and a granulated-agglomerated body made of triturated particles. The champagne cork stopper is a product very typical of Catalonia, as 60% of worldwide production is concentrated in this region. This occurs because of the production of cava in the same region and because of champagne production in nearby France.

## *Part IV: Integrated evaluation of the cork sector and improvements from an industrial ecology perspective*

**Part IV** contains **Chapter 7** [*Environmental analysis of the cork sector in Southern Europe (Catalonia – Spain) from an industrial ecology perspective*] which attempts to integrate the results of the forestry and industry systems for the products analysed in Part III. There is a discussion about allocation procedures in the systems and about carbon fixation associated with cork products. Finally, potential future strategies for environmentally improvements are proposed for all the systems studied at different levels from an industrial ecology perspective.

## *Part V. Conclusions and Future research*

**Part V** includes **Chapter 8** and provides the general conclusions of the dissertation and proposes future fields of research associated with the cork sector.

[*Note:* Each chapter from 3 to 7 presents an article –either published or under review-. For this reason, an abstract and a list of keywords are presented at the beginning of the chapter, followed by the main body of the article].

# PART I

## INTRODUCTION TO THE DISSERTATION

Chapter 1: Introduction

Chapter 2: Methodology

# Chapter 1

# INTRODUCTION

**Chapter 1** introduces cork oak trees, cork oak forests and cork as a raw material Then it shows where in the world cork is found: mainly in the Iberian Peninsula, and in Catalonia in particular. Before that, to justify the dissertation and explain its objectives, the cork sector is introduced and divided in two parts: the forestry and industry sectors.

This chapter is structured as follows:

- Overview of the cork resource.
- Overview of the cork sector in Catalonia.
- Justification to the dissertation.
- Objectives of the dissertation.

# 1. Introduction

Changes that are occurring in the global economy, manifested in globalisation and technological change, are causing society to be increasingly conscience of the importance of reducing the impacts of man's activities. For this reason, new challenges are being faced to move towards sustainability in different areas and on different levels. According to the Brundtland Commission of the United Nations on 20 March 1987, sustainable development (SD) is "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" [1]. SD is usually presented as the intersection between environment, society and economy, which are conceived of as being separate but connected entities (Figure 1.1) [2].

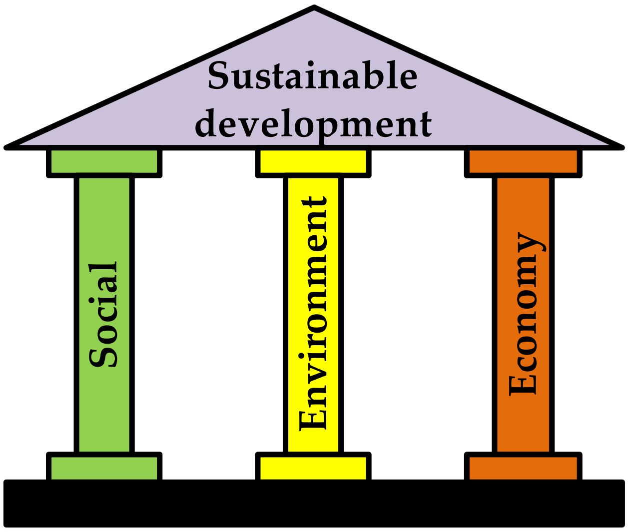



**Figure 1.1. A popular way of representing Sustainable Development (SD).** ***Source: [3].***

The term industrial ecology (IE) refers to a set of tools, principles, and perspectives borrowed and adapted from ecology for the analysis of industrial systems including their impacts on society and the environment of the systems' material, energy, and information flows [4, 5]. IE explores the following assumption: the industrial system can be seen as a certain kind of ecosystem [6, 7]. Figure 1.2 presents an analogy between ecosystem and industrial systems. IE perspectives can help to optimise systems because the approach is focused on holistic strategies for prevention and planning of more environmentally sensitive industrial development, and not on the perspective of 'end-of-pipe' pollution control methods [8]. In this sense, IE tries to move from a linear to a closed-loop system in all the realms of human production and consumption. In this and other ways the world can move closer to an ecological model in its dynamics [9].

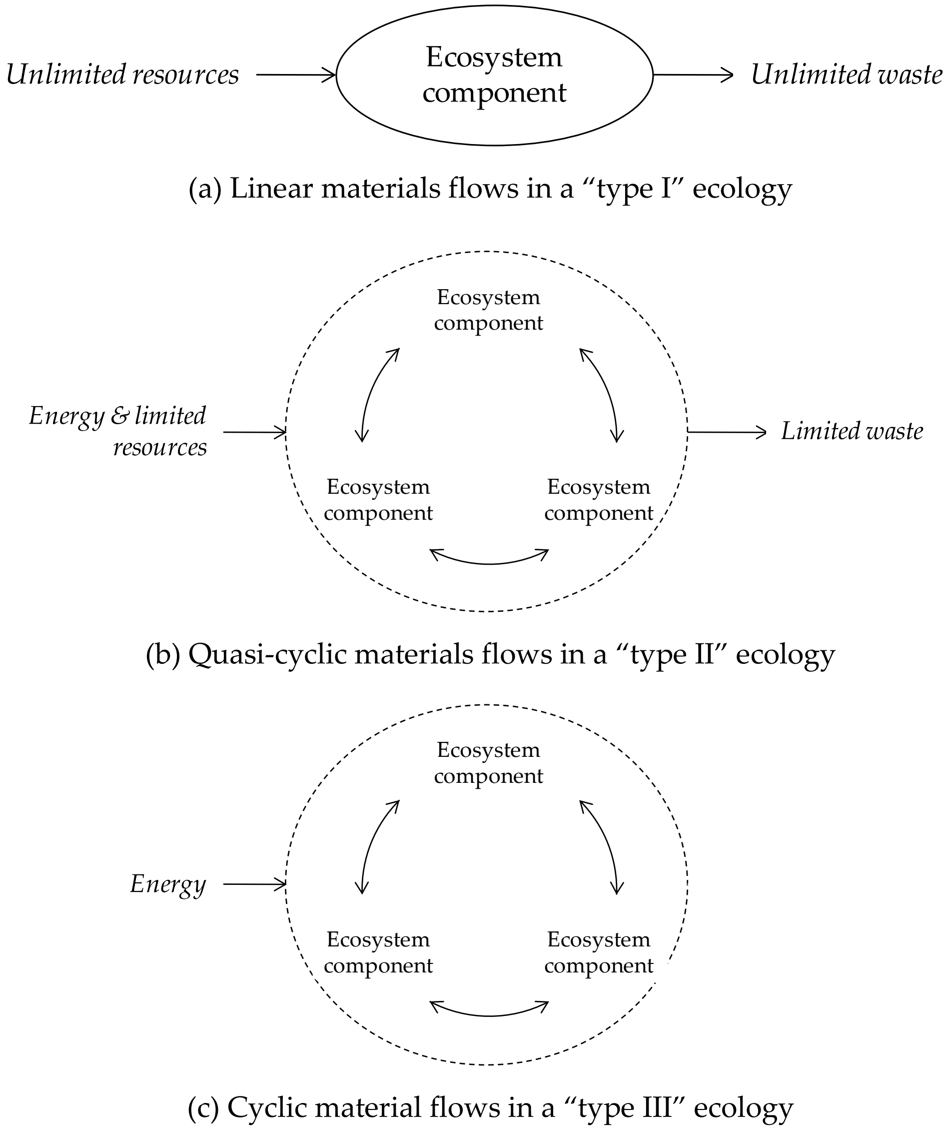



**Figure 1.2. Analogy between ecosystems and industrial systems.** ***Source: [5].***

Cleaner production would be that productive activity that uses preventive environmental strategies and techniques to reduce the amount of pollutants and hazardous substances to avoid risks for both humans and their environment [10]. Cleaner production is achieved by applying experience, renewing technology and changing attitudes. That is to maximize energy efficiency, save raw materials and reduce maximum levels of contamination, which often means being more competitive [11].

The cork sector is a traditional part of the economy in south-western Mediterranean areas such as Catalonia (Northern Spain). This sector already contributes to sustainability by making products with cork; a material of organic origin that is renewable and local. In addition to this, the cork sector in Catalonia would like to move towards economic, social and especially environmental sustainability by generating new knowledge, and improving its current productive systems by employing cleaner production strategies. The cork sector perceives the environment as something inherent to its raw material, but besides, it is continuously trying to improve on an environmental level. In order to accomplish this objective, it is necessary to get to know the area more extensively, as well as carry out studies and provide data that could enable the development of strategic decisions to improve existing systems from the industrial ecology perspective.

At the moment, different actors of the cork sector in Catalonia such as the Catalan Cork Institute (ICSuro) [12], the Association of Cork Companies of Catalonia (AECORK) [13] and more than 10 cork enterprises and 5 cork forest owners are involved in a research project that would be the first step towards sustainability in the sector. The four-year project CENIT-DEMETER (2008-2011), "*Desarrollo de Estrategias y Métodos vitícolas y Enológicos frente al cambio climático*", and its sub-activity 7.2, associated to the environmental evaluation of the cork sector try to support criteria and data for the future strategic development of the sector. Additionally, many of the cork companies are starting to think about implementing strategic tools for this purpose such as ecodesign, ecoinnovation, cleaner production and even carbon footprint ecolabel implementation.

## 1.1. Overview of cork resource

The next section presents an overview of cork oak forests, the cork oak tree and cork as a resource. First, cork oak forests and the cork oak tree will be introduced explaining some of their unique characteristics and emphasising the environmental roles that this tree has. Following this, cork will be introduced briefly focusing on its physical and chemical composition, the types of raw cork materials that can be obtained from the tree and pointing out some of the products that are being produced with cork. Several photographs of cork and the cork oak tree (*Quercus Suber L.*) cycle are shown in figure 1.3.

(a) Cork oak tree under 40 years (not previously exploited)

(b) Cork oak tree being stripped

(c) Cork oak tree after stripping

(d) Cork piled up at a forest collection point

**Figure 1.3. The cork oak tree cycle and cork as a resource.** ***Source: Jesús Rives.***

## 1.1.1. Cork oak forest

The first cork oak trees occurred millions of years ago. It is thought that during the Pleistocene (around 1.8 million years ago) the geographical distribution of the cork oak and its genetic diversity was influenced causing the species to be located in areas with a more benign climate. More specifically, cork oak forests got their present distribution areas 10 thousand years ago [14]. Since then, these forests are typical of the Western Mediterranean region, occurring spontaneously in the territories that can be observed in figure 1.4 due to their adaptation to the geographical area and, of course, the environmental conditions [15]. Table 1.1 shows some basic environmental parameters related to cork oak forests.

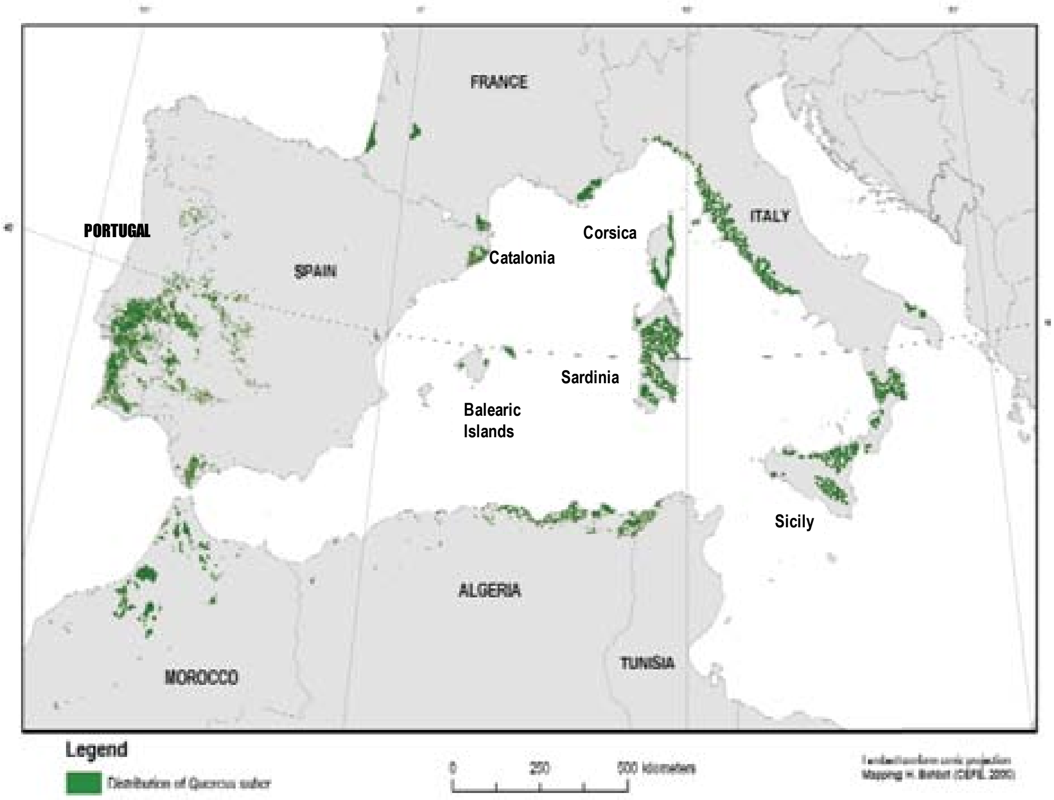



**Figure 1.4. Cork oak distribution in the western Mediterranean.** *Source: Adapted [16].*

The real area of the distribution of cork oak forests is not known exactly, but worldwide it is estimated that it occupies a surface of between 2.3 - 2.4 million hectares, and that about 300,000 - 374,000 tonnes of raw cork is extracted yearly [17]. This uncertainty is understandable because data was estimated from the individual registers of different countries, with their respective methodologies and with different year references. Furthermore, as cork is a natural resource, to obtain quality data requires a great deal of fieldwork to analyse a lot of territory or the development of mathematical models. Accounting with basic quality data about the Mediterranean cork sector is fundamental in order to carry out good future research and enable strategic planning.

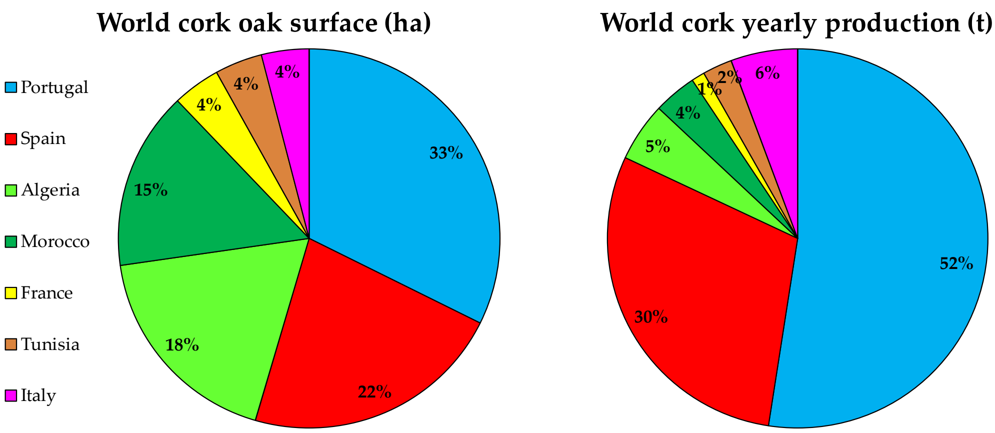



**Figure 1.5. Cork oak distribution in the western Mediterranean.** *Source: [18].*

Cork oak forests are concentrated in 7 countries (Figure 1.5), and 88% of their surface area is located in Portugal (33%), Spain (22%), Algeria (18%) and Morocco (15%). The production of cork is mainly concentrated in Portugal (52%) and Spain (30%).

On the other hand, analysing the worldwide cork production annually it can be observed that the Iberian Peninsula concentres 82% of this production: Portugal (52%) and Spain (30%) [18]. In spite of the considerable world surface area in Algeria and Morocco only 5% and 4% of cork is produced in these countries respectively. This fact could be because cork oak forests in North Africa are quite young relative to the forests in the Iberian Peninsula as many of them was planted under a forestation programme established by the French colonial administration when the area was under their control [19]. Besides, this low numbers could also be consequence of no recent inventories having been carried out [17].

**Table 1.1. Cork oak tree basic environmental conditions.**

| Aspect | Description | Reference |
|---|---|---|
| Latitude | 31º N – 45º N | [17, 25] |
| Longitude | 9º11′ W – 15º E | [25] |
| Altitude from sea level | 0-2000 metres (optimal 600 m) | [25] |
| Mean annual precipitation | 600-1000 mm. (it can survive under 400 mm) | [17, 25, 27] |
| Mean annual temperature | 13-16ºC. (can survives up to 19ºC) | [16, 28] |
| Type of soil | very tolerant: siliceous and sandy soils | [27] [17] |
| Soil pH | acidic soils: 4.8 and 7.0 | [17, 29, 30] |

In 2009, Portugal accounted with more than 800 companies comprising more than 12,000 workers involved in the cork sector [18], while more than 330 companies and 3,500 workers were involved in Spain [20]. Geographical localisation of cork industry is obviously linked to the area were the cork raw material is extracted and for this reason the cork industry sector is mainly concentrated in the Iberian Peninsula. In Portugal the industry is concentrated mainly in the north-western region; especially in the Aveiro district, while raw cork material extraction is mainly concentrated in the central-south region; Alentejo region produces 72% of the resource [18]. A similar trend is observed for Spain, where the industry is mainly located in the north-eastern region (Catalonia), while the south of the country, the regions of Andalusia and Extremadura concentrate most cork extraction; 85% [21]. In Spain, the concentration of cork industry in Catalonia is a consequence of, first, the development of the parallel development of wine and champagne production in France [22]. The concentration of cork extraction in southern Spain could be for different reasons, but one of them is most likely the more frequent period of cork extraction in the south because of better environmental conditions [15]: in

Catalonia cork is extracted from trees every 12-14 years [23], while in Andalusia and Extremadura the period is around 9-10 years [24].

The development of cork oak forests has been attempted in other regions of the planet such as California, Uruguay, Australia, Bulgaria and Japan, but the difficulty of seed conservation, the field establishment of young plants, slow growth and the long life cycle, never allowed for more than a few stands and scattered trees [25, 26].

It is estimated that diversity of species in Spain is about 85,000 taxons [31]. Cork oak is an endemic tree species in the western Mediterranean. Cork oak forests are considered High Nature Value Farmlands (HNVF) [32] and are included in Annex I of the European Union Habitats Directive (92/43/CEE) [33]. These forests are especially valuable for their high degree of biodiversity [31, 34], and because cork extraction has positive benefits for biodiversity and it is compatible with the maintenance of the great ornithological value of cork oak forests [35].

Cork oak forests also have a relevant role to play against desertification and for soil conservation. This aspect is fundamental for the future viability of these ecosystems. The soil is richer in organic matter and is characterised for having better infiltration, water storage, nutrient retention, aeration and root growth capacities. The cork oak leaves are renewed yearly, this means that old leaves, fruits, small branches and animal excrement accumulates and decomposes in the soil returning nutrients and organic matter to the system [14]. By promoting the infiltration of rain and preventing soil erosion, cork oak forests also contribute to hydrology cycle regulation [14, 36].

The profitability of cork oak forests requires correct management to guarantee the persistence of the species, biodiversity and productivity, at the same time as other ecological, economical and social benefits are obtained which impact society. Forest management plays a key role influencing the thickness and quality of raw cork: optimal cork oak management should be oriented towards the periodical removal of cork according to established legislation; in addition this would contribute to the sustainable management of these forests [37]. Treatments reducing stand density stimulate vegetative activity and production of cork slabs with thickness suitable for industrial processing [37].

Most of the present cork oak forests appeared from mid 19th century due to the increasing value of cork, as well as the demand for cork stoppers [14]. These forests provide multiple economic activities, such as livestock grazing, hunting, mushroom collection and honey production, but most of their economic value derives from cork extraction [16, 38]. Besides the extraction of cork and other goods, these forests afford other services to society such as private amenities and public recreation opportunities [39], and providing numerous indirect environmental services: wildlife habitat, soil erosion prevention, carbon storage, hydrology regulation, etc. Without the cork incomes, these forests would collapse economically, causing serious ecological and social consequences [40] such as the substitution of this ecosystem by others that while more lucrative would cause the loss of regional employment [41].

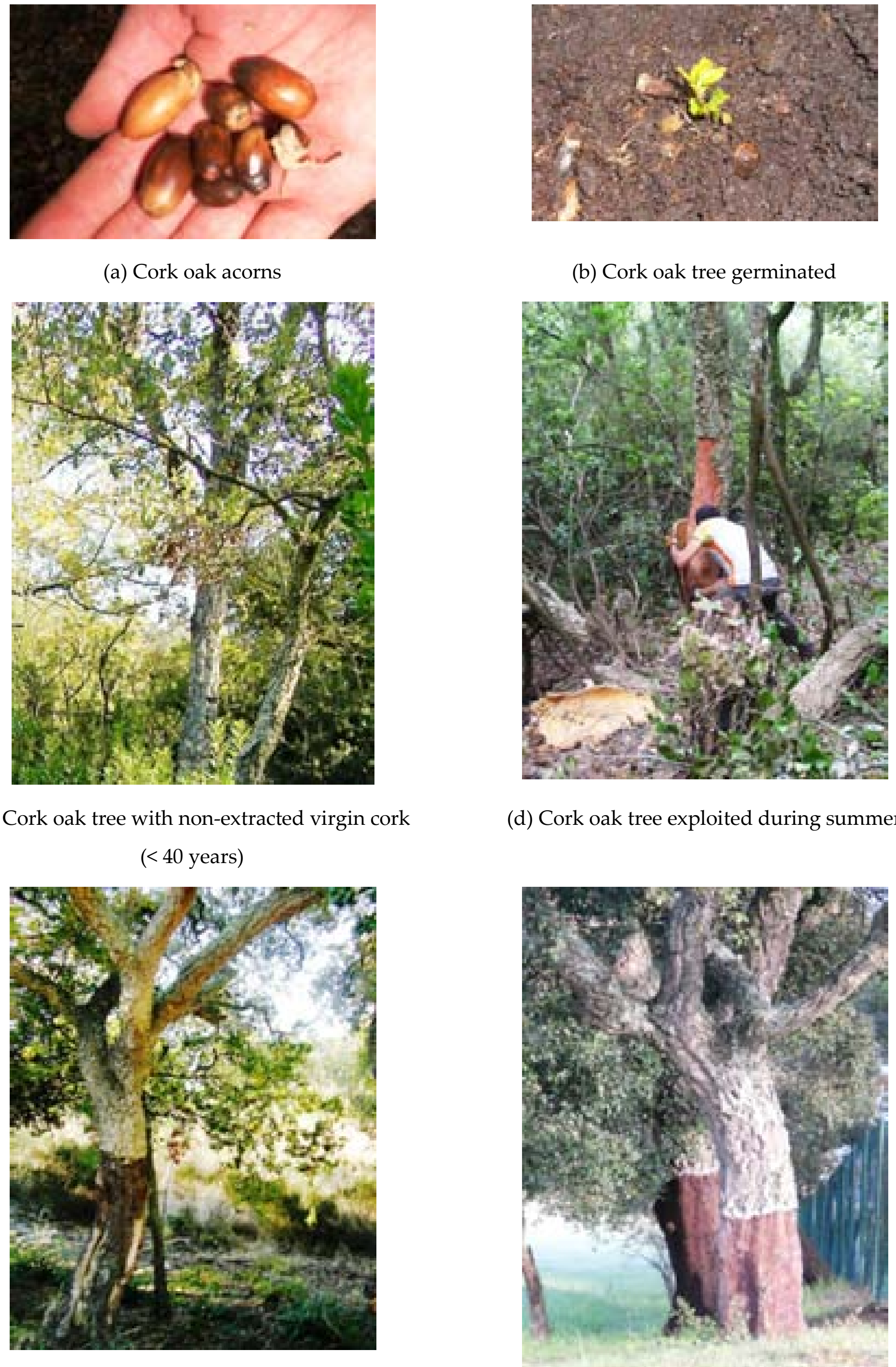
If the forests are managed adequately cork production can be guaranteed for the future. Nowadays, there are different certification labels of sustainable forest management. Certification is a process of forest management evaluation used as an assurance of quality. Specifically, it indicates that the certified product was made under an established set of criteria and indicators aimed at promoting sustainable forest management [42]. The criteria for verification describe social, economic and ecological aspects to preserve the forests for present and future generations. The certification processes are realised by independent, non-profit and non-governmental organisations that have established a globally recognised system of independent forest certification and product labelling to help consumers identify products from responsibly managed forests.

Several sustainable forest management certification schemes have been developed, but nowadays the certification of the Forest Stewardship Council (FSC) [43] and the Programme for the Endorsement of Forest Certification (PEFC) [44] are becoming the most extended and widely implemented for cork oak forests. Currently, in Portugal there are approximately 15,000 hectares of cork oak forests certified by FSC, 2% of the total surface area; and forestry associations have estimated that they are due to reach 150,000 ha in the near future [14]. In Spain, there are 26,000 ha certified by FSC [45] and 15,572 ha by PEFC [46]: this means that 8% of the total Spanish surface area is certified.

## 1.1.2. The cork oak tree

The cork oak tree (*Quercus Suber L.*) is a native, endemic and evergreen species, from the Fagaceae family, that grows in western Mediterranean schlerophyllous forests. It is usually between 18-20 metres tall, with a broad, round-topped head and a glossy green colour [47]. The leaves are 4 to 7 cm long, weakly lobed or coarsely toothed, dark green above, paler below, with the leaf margins often down-curved [48]. The acorns are 2 to 3 cm long, in a deep cup fringed with elongated scales. Cork oak trees can survive for centuries [48]; between 250-350 years [17]. This species is special because it is has an thick outer bark formed by a continuous layer of suberised cells that constitute the external envelope of the stem and branches [49] known commonly as cork, that is a natural, renewable raw material and local to Mediterranean areas. Figure 1.6 presents several images of cork oak trees and their main growth stages.

The cork oak tree has the capacity to survive a scarcity of water during summer, and is well adapted to this condition by reducing its transpiration and accounting with a system of deep roots that allow it to obtain water from the subsoil [14, 50]. The cork oak tree is expected to be severely affected by climate change due to the increased intensity and duration of the drought periods expected for this region [51] and especially because of its high sensitivity to drought in the initial stages of its development [36].



(a) Cork oak acorns

(b) Cork oak tree germinated

(c) Cork oak tree with non-extracted virgin cork (< 40 years)

(d) Cork oak tree exploited during summer

(e) Cork oak trees bark re-growth

(f) Old cork oak trees exploited

**Figure 1.6. Cork oak trees and main growth stages.** ***Source: Jesús Rives.***

Another important fact that characterises the cork oak tree is its resistance to fire. In fact, it is thought that the outer bark of the tree could have been an evolutionary adaptation to a Mediterranean climate where fire was an important ecological factor [14]. After a fire, while many of the other tree species merely regenerate from seeds or resprout from the base of the tree; the cork oak branches, protected by cork, quickly regrow and recompose the tree canopy [52]. This is a clear advantage compared to other species that after a fire return to an initial stage of development [14]. Cork extraction is a key factor determining post-fire cork oak survival: unstripped trees present the highest survival rates, while the trees that have been recently stripped are the most susceptible to die if a forest fire occurs [53, 54].

## 1.1.3. Cork bark

The cork oak has two meristemic tissues: the cambium that is usual in all forest plants that produce xylem inside and phloem outside, and the phellogen or cork cambium that generates the phelloderm inside and the periderm outside [25]. Thanks to this particularity, the cork oak's bark is composed of two parts: an inner bark called phloem, and an outer bark called periderm [26]. Unlike the inner bark, the outer bark is not vital to the tree's survival, and can be removed periodically without causing damage to the tree because the inner bark has the capacity of develop a new outer bark [14]. The outer bark separates the living cells of the plant from the outside environment [26]. The phellogen die after cork removal but a rapid formation of a traumatic new phellogen takes place. This response of the tree is repeated whenever necessary, and this is the reason for a feasible and sustainable exploitation of the cork oak tree for its cork [16]. After each bark stripping a new phellogen is differentiated within the secondary phloem and at each season of growth a new cork-ring is added to the regenerated phellem [15]. Figure 1.7 presents a schematic diagram of a cross-section of cork oak tree trunk.

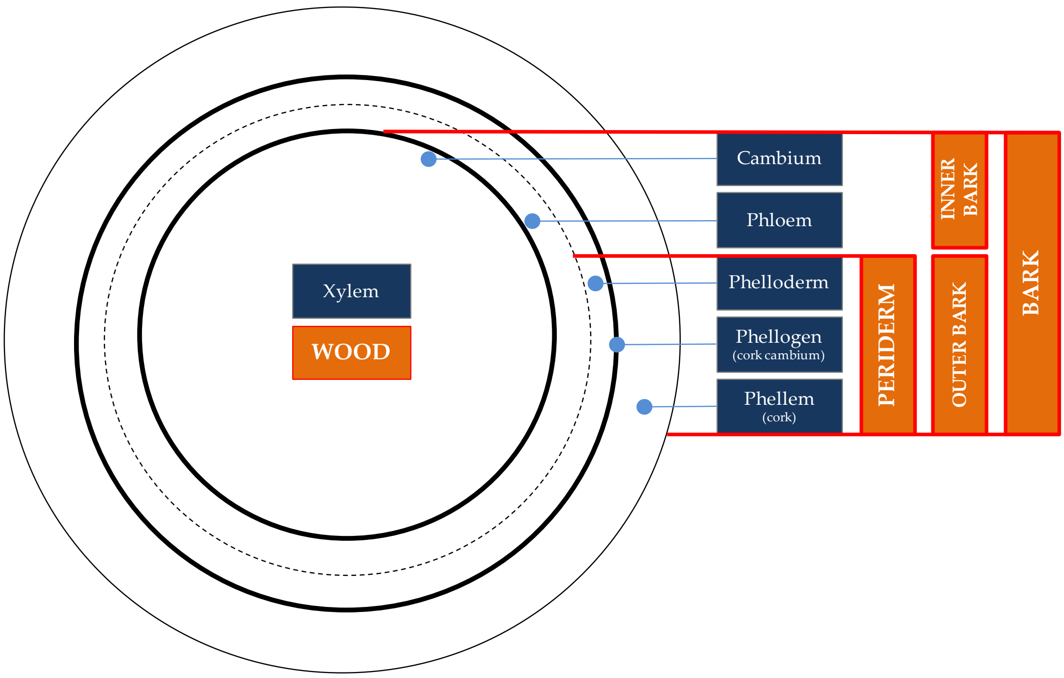



**Figure 1.7. Schematic diagram of a cross-section of a cork oak tree trunk.** ***Source: adapted from [26] and [25].***

The suberised bark seems to be an adaptation to environmental conditions to protect the tree from the heat and dry winds of the Mediterranean summer [47]. When cork is extracted, at the end of spring and during summer, it is fundamental that the phellogen cells responsible for cork production maintain their activity and continue dividing themselves, and it is also essential that the tree's tissues stay hydrated , especially in the dry Mediterranean summer [14]. Cork-ring widths of cork oak trees have proved to be very sensitive to year-to-year climatic variability; this is especially true because of the high sensitivity of the phellogen to climatic factors such as monthly rainfall and mean temperature. [15].

The outer bark has special characteristics of development, regularity, growth intensity and longevity that singularise this species [26]. The periodical extraction of cork not affect the radial growth of the tree [55]. The stripping height (SH) is the distance between the floor and the maximum height that can be stripped. This distance is determined by a specific debarking coefficient (DC) and the circumference at breast height (CBH) [56]. Equation 1.1 presents how SH must be calculated. According to the DC, for a cork oak tree that is exploited for the first time only the double of its circumference at breast height can be extracted.

$$SH = DC \times CBH$$

- For first cork extraction, DC cannot be over 2 (CBH must at least above 65 cm ≈ 20 cm of diameter).
- For second cork extraction, DC cannot be over 2.5
- For successive cork extractions, DC cannot be over 3.

**Equation 1.1. Stripping height determination according to debarking coefficient (DC) and circumference at breast height (CBH).**

## 1.1.4. Cork as a raw material

As a resource extracted directly from a tree, cork is a natural raw material, and the periodical regeneration of the tree [57], makes cork a renewable resource. Cork is composed of dead cells with walls that are impermeable due to a chemical compound known as suberin which is responsible for the unique and remarkable properties of cork [58]. In fact, all trees produce layers of suberised cells to protect themselves, but only the cork oak tree has the capacity to regenerate its outer bark by adding annual rings of cork [14].

The main components of cork are 40% suberin, 22% lignin, 20% polysaccharides (hemicelluloses and cellulose), 15% extractives (waxes and polyphenols), and 1% ash [59, 60]. The elemental chemical composition of cork is 67% carbon, 23% oxygen, 8% hydrogen and 2% nitrogen [25].

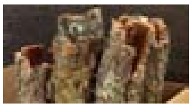
The unique chemical and physical properties of this raw material include its low density, low permeability to liquids and gases, elasticity, compressibility, resilience, chemical inertness, good heat and acoustic insulating properties, resistance to microbial growth and an ability to adhere to a glass surface [60, 61]. Table 1.2 shows some of the particular properties of the cork raw material.

**Table 1.2. Main properties of cork as a raw material.** ***Source: Adapted from [25, 62, 63].***

| **Property** | **Description** |
|---|---|
| Density | 120–200 kg $m^{-3}$. |
| Humidity | At 20ºC and 65% relative humidity of the environment, the cork humidity is about 6% because of the low density of the material and the high quantity of gases contained in its cells. |
| Specific weight | Very low: the average is 0.18 g $cm^{-3}$, but it ranges from 0.12-0.24 g $cm^{-3}$. |
| Impermeability | Very impermeable. It absorbs less than 18-20% of the water fact that favours the conservation of the material and its avoidance of rot. |
| Floatability | Very high. The high quantity of air in the cells and their permeability make cork an excellent floating. |
| Compressible | Very high. A natural cork stopper of 24 mm in length can be compressed to 16 mm. |
| Flexibility and elasticity | The limit of elasticity is approximately 5 kg $cm^{-2}$. |
| Resilience | It is a material resistant to elasticity for years. |
| Odour and flavour | Neutral. For this reason, it can be used for packaging food products. |
| Heat conductivity ($\lambda$) | 0.040–0.045 $Wm^{-1}K^{-1}$. |
| Thermal diffusivity ($\alpha$) | $1{\cdot}10^{-7}$–$1.5{\cdot}10^{-7}$ $m^2s^{-1}$. |
| Flammability | It is very difficult to ignite and poorly combustible because it needs a lot of oxygen to burn. However, cork dust can be used as a combustible in boilers. |
| Acoustic isolating | It is very absorbent of sound for low and medium frequencies. |
| Percussion insulating | Good insulating properties for acoustic percussion; for this reason it can be used in laminate flooring. |
| Vibration insulating | Excellent to cushion vibrations. |
| Electrical insulating | Excellent electric insulator. |
| Heat of combustion | Between 6,500-7,000 kcal $kg^{-1}$ (similar to vegetal coal). |
| Durability | Very high. Cork is difficult to alter. |
| Oxidation | Does not rust due to the action of air or humidity. |
| Malleability | Easily workable, especially if the cork has been previously boiled. |
| Friction | Good resistance to movement and friction. |

Up till now, it has called cork a unique type of raw material obtained from the cork oak. However, the term *cork* is generic and includes different raw materials that present similar characteristics but have some differences between them. Usually, cork is removed from the tree as single pieces of cork commonly called cork slabs. Table 1.3 presents the different raw cork materials:

**Table 1.3. Raw cork materials from the cork oak tree.** ***Source: Adapted from [25] and [64].***

| Type of cork | Description |
|---|---|
| Virgin cork  | The first-generation cork produced by the original phellogen, which is stripped from the cork oak when the tree is 25-40 years old depending on the region where the forest is located. The back of the cork, the outer part of the raw material, is very rough and presents deep cracks, while the belly, the inner part, is very irregular. |
| Second cork  | Second cork is the cork extracted after virgin cork. This is between 8-14 years later, again depending on the region where the forest is located. Second cork contains deep fractures, and it is of better quality than virgin cork but is still irregular. |
| Reproduction cork  | This is the third and subsequent cork to be extracted. It has a more regular cellular structure and higher quality and is the preferred raw material for the cork industry. After obtaining virgin cork and second cork, all the cork produced by the tree will be called reproduction cork. However the best reproduction cork is obtained from the forth stripping. The reproduction cork can be obtained more than 10 times during the lifespan of the tree. |
| Virgin winter cork  | This raw cork material is obtained during winter from dead trees or branches that were pruned. This resource is the consequence of forest management during winter, and represents a very low quantity compared with virgin, second and reproduction cork. |
| Fragments of reproduction cork  | This type of cork is the same than reproduction cork but in little pieces of under 400 $cm^2$. These fragments are also collected and destined to be triturated. |
| Cork with defects  | This type of raw cork includes that cork that presents irregularities because of various causes such as insect activity, bird activity, because the phellogen of the tree was damaged in a previous stripping by axes, and so on. |
| Fired cork  | Sometimes fired cork is also collected and sold at a very low price for insulation applications. |

Besides the classification by type of raw cork material, cork slabs are classified by quality categories. This is specially carried out for reproduction cork which is the raw material used to make products out of solid cork [60]. The remaining cork raw materials: virgin cork, second cork, virgin winter cork, fragments of reproduction cork, cork with defects and fired cork are granulated and then agglomerated before becoming a product. This group of cork resources will be known during this dissertation under the generic term *cork by-products*. These raw materials are unavoidable and in spite of their low economic value compared with reproduction cork they are also a very useful material [65]. In 2009, reproduction cork had a price 5.6 times higher than cork by-products [18].

## 1.2. Overview of the cork sector in Catalonia

Catalonia is a nationality, constituted as one of the seventeen autonomous regions (known as communities) of Spain. It is situated in the north-eastern part of the Iberian Peninsula bordering France and Andorra in the north, and occupying 32,114 km$^2$. From the second half of the 18th century, the extraction of cork and its subsequent transformation into many products has been a traditional craft activity in Catalonia. Over time, little workshops became industrial plants, and currently a specific cork cluster is developing in this area [21]. In fact, the sector does not extend throughout the region as it is located in a particular area: the north-east of Catalonia, between the Costa Brava and the Catalan Pyrenees.

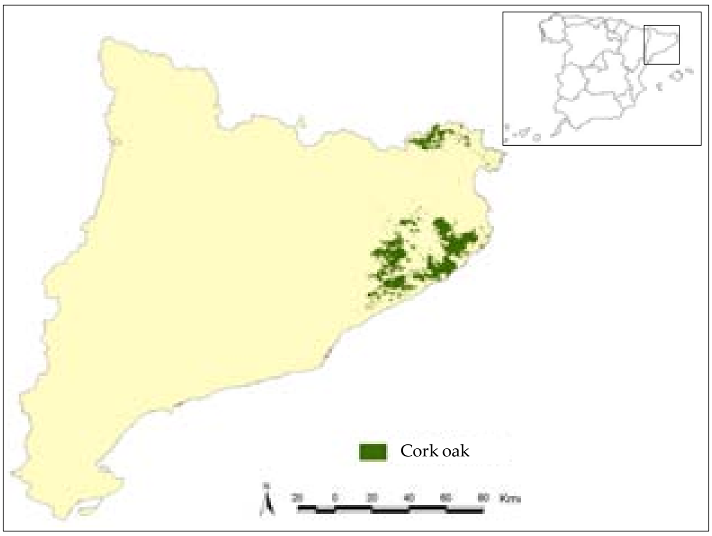



**Figure 1.8. Cork oak distribution in Catalonia (Northern Spain).**

The cork industry originated in Catalonia as small craft workshops that manufactured cork stoppers mainly exported to France, where there was a significant production of wine and champagne [21]. In the second half of the 19th century the production started to be industrialised. Later, in the late 19th century and during the first quarter of the 20th century, the Catalan cork industry reached its heyday coinciding with the start of the local cava industry, which acts as a large fostering sector. The large volume of production allowed for high levels of mechanisation and a highly competitive position. During World War II, the industry suffered a decline in international demand, but later when the crisis ended the sector again became more internationalised. By the 70s and 80s, Portuguese and southern Spanish competition became stronger, and some Catalan companies opened subsidiary companies in the south of Spain to control the chain of value and secure raw materials.

The chain of production of cork can be divided in 3 subsectors with their respective players: forestry cork sector, industry cork sector and regional cork institutions (Figure 1.9). The following subsections will go deeper into these groups individually because of the clear division in the Catalan cork sector.


**Figure 1.9. Organisation of cork sector in Catalonia.**

## 1.2.1. Forestry cork sector

The forestry cork sector is a heterogeneous group of actors. In Catalonia, all cork oak forests are private and have a landowner or proprietor. Typically, each forest is managed by a familiar company which passes the property from generation to generation. Good and balanced management of the forest supposes profits all the time, whereas if exploitation starts from zero a long period and investment are required to achieve quality reproduction cork. This long-term profitability and the high initials costs of cork forests are one of the main reasons why it is difficult for new player (individuals or families) to enter to the cork forestry business. Some of the proprietors are affiliated to the Catalan Association of Forest Owners (CFC), which is a private and independent association that watches over the interests of the forestry sector in Catalonia founded in 1948 [66], but in general cork oak forest proprietors are individuals. At the moment, more than 50% of the cork oak surface area in Catalonia is not exploited [56].

Cork oak forest activities are intended to obtain cork and other complementary harvests such as honey, pine nuts, firewood, shrubs for decoration, medicinal plants, mushrooms, and so on. In spite of the wide range of different commodities that can be obtained, cork is the most significant because it is extracted in higher quantities than the other resources, and because it represents the highest in terms of economic profitability [39]. In fact, it could be affirmed that practically all the activities performed in these forests are a consequence of cork extraction.

Basically two different agro-forestry system models of cork exploitation can be found: silviculture and forest model [17]. In Catalonia the *forest model* is the most representative. Table 1.4 summarises the main characteristics of each model.

**Table 1.4. The main characteristics of the two cork exploitation models: silviculture model and forest model.** ***Source: Adapted from: [17, 20, 23, 42, 67] .***

| Characteristics | Forest model | Silviculture model |
|---|---|---|
| Most representative localisation | Catalonia, France and Italy | Portugal "*Montados*", southern Spain "*Dehesas*" |
| Type of exploitation | Extensive | Intensive |
| Forest structure | - Usually more than 80% of the trees are cork oaks.<br>- Other tree species such as pines, oaks or holm oaks could be found<br>- Trees of different ages are mixed on the same plot<br>- Heterogeneous system | - All the trees are cork oaks of a similar age<br>- Homogeneous system, well organised<br>- Trees of same ages are founded on the same plot |
| Type of germination | - Completely natural (regeneration)<br>- Trees are only planted when a natural disaster such as a forest fire or an outbreak of pests has occurred | - Artificial.<br>- Trees are planted because livestock does not allow for natural regeneration |
| Other uses of the exploitation | Other forestry resources in small quantities: honey, firewood, shrubs for decoration, pine cones, and so on | Pasture for livestock grazing and agricultural crops |
| Quantity of trees per surface | 400 trees/ha | 50-150 trees/ha |
| Period of extraction | Every 12-14 years | Every 9 years |
| First cork extraction | 35-40 years | 25 years |
| Cork extracted | 150/kg/ha/year | 200 kg/ha/year |

Cork oak distribution in Catalonia can be observed in figure 1.8: it occupies about 116.000 ha, but the species is dominant only in 63,000 ha of this surface area [23]; this is about 12% of all Spanish territory [68]; the forest areas where the species is dominant and represents more than 80% of all trees, and areas where the cork oak is not dominant and is mixed with other tree species; specially pines, holm oaks and oaks [56]. Moreover, in 2010, 6,139 ha of these areas were certified by PEFC : practically 10% of all the Catalan cork oak forests [44].

## 1.2.2. Industry cork sector

The industry cork sector is composed of private companies. According to the *Registre Mercantil* of Catalonia, the industry cork sector accounts for more than 85 companies, invoicing more than 230 million euro in total [21]. Most of the companies are limited liability companies and others are S.A corporations. There are different types of industries depending on the activities that they perform. Also, there are companies that have the capacity of perform more than one activity.

In general the industry cork sector can be divided into the following groups [21], and figure 6.1 clearly illustrates the structure of the cork sector according to its main products:

- **Preparation cork industries (or auxiliary cork industries)**: their main activity is to transform the raw cork slabs from the forest that have not been previously treated into prepared cork slabs (Figure 1.10). These auxiliary companies generate an intermediate product that will later be transformed into an end product. In most cases, industrial preparation plants are situated near the forests where the raw cork material is extracted. In Catalonia, most of the end-product companies integrate preparation into their activities. But, it is frequent that Catalan companies have preparation subsidiary companies in the south of Spain in order to provide prepared raw materials or that at least, buy raw materials from other companies in the south of Spain and Portugal that are specialised in cork preparation. The import of raw cork from these territories is fundamental because it is estimated that cork oak forests in Catalonia only provide 10% of the raw material required by manufacturers [20], however this percentage could be doubled in future if the currently abandoned forests start to be managed [56].

(a) Raw reproduction cork slabs after transportation from the forest

(b) Reproduction cork slabs after preparation (intermediate product)

**Figure 1.10. Reproduction cork slabs before and after preparation.** ***Source: Jesús Rives.***

- **Natural cork producers:** this group of producers generates products directly from the prepared cork slabs, without triturating the material: this is the generation of single pieces of cork made from solid cork [69]. The two main products made as individual pieces of cork are the natural cork stopper that is an end product (Figure 1.11), and the natural cork disc that is an intermediate product that is used to produce technical stoppers joined with cork body agglomerates. The natural cork stopper is the main objective of the sector [19, 69-71] and it is used to put the top on wine bottles, especially in the case of quality wines. This cork subsector will be detailed further in Chapter 4.

(a) natural cork stoppers (end product)

(b) natural cork discs (intermediate product)

**Figure 1.11. Natural cork products: stoppers and discs.** *Source: Jesús Rives.*

- **Granulate cork producers:** the main activity of this industrial subsector is the transformation of forestry cork by-products and wastes from the natural cork industry into small particles of cork of between 0.25 mm and 8 mm [72]. Cork granulates (Figure 1.12) are an intermediate product that with adhesives or other binding techniques such as temperature, will form agglomerated products. In general, two types of cork granulates can be found: white cork granulate generated mainly from natural cork industry wastes that will be used in the technical stopper industry; and the black cork granulate generated from forestry cork by-products and used for decoration, construction, insulation material, and other non-food applications. This cork subsector will be explained in more detail in Chapter 5.

(a) Cork granulate production (intermediate product)

(b) Cork granulate (intermediate product)

**Figure 1.12. Cork granulate.** ***Source: Jesús Rives.***

- **Technical stopper producers:** This subsector uses white cork granulate and natural cork discs to generate cork stoppers. A wide variety of technical stoppers exists [73], with different diameters and length, different granulate grain size, combined with other materials (wood, plastic), with different glues, etc. Some of them that are composed only with granulated-agglomerated cork, while others are joined with natural cork discs. Technical stoppers sometimes are an economic solution for use instead of natural cork stoppers to put the top on still wine bottles, and in other cases they are used to retain the high internal pressures in gaseous or sparkling beverage bottles [74]. The most famous technical stopper is the champagne cork stopper (Figure 1.13). More about this subsector will be explained in Chapter 6.

(a) Champagne cork stopper (end product)

(b) Microgranulated cork stopper for still wine (end product)

**Figure 1.13. Technical cork stoppers: champagne cork stoppers and microgranulated cork stoppers.** ***Source: Jesús Rives.***

- **Speciality and other cork goods producers:** this subsector comprises different applications that are produced by some companies in Catalonia, but that comprise lower productions than the cork stopper subsectors. In fact cork stoppers comprise 98% of the total invoiced in Catalonia, while other goods represent just 2% [20]. This is because only a few small companies manufacture products other than stoppers, and because some of these other cork products are of very low value. Many other products are manufactured from this ecomaterial [22, 75-77]. Cork has been applied in agglomerated panels for construction [25, 78, 79] in thermal-protection systems for spacecraft, structural elements for light aircraft [80-82], thermal and acoustic insulation [73], flooring and wall panels [77], decorative and fashion purposes such as clothes, chairs, furniture, hats, wallets, sandals and so on [83]. The Portuguese Pavilion at the Hanover Expo 2000 in Germany [22] and at the Shanghai Expo 2010 in China [84] was composed basically by cork. Figure 1.14 presents two examples of cork specialities.


(a) Cork granulated-agglomerated insulating panel (end product)

(b) Cork board (end product)

**Figure 1.14. Cork goods specialities.** ***Source: Jesús Rives.***

In spite of the great opportunities that cork offers, some producers started to substitute cork with synthetic polymers and other raw materials in different applications some time ago. For example, in the case of natural cork stoppers two important competitors are now to be found: synthetic closures and the screw caps. The reasons why some wineries decided change to these alternative stoppers are numerous, but some of them could be the marketing of these alternative stoppers at a cheaper price, and especially cork taint - the presence of trichloroanisoles (TCA) in wine [59, 85, 86]. However, the cork sector has tried to solve cork taint problems and at the moment it is a seems to have reduced markedly [87] and it has been found that while TCA can come from cork, it can also come from other sources such as contamination of the winery or bottling equipment, airborne moulds as well as chlorine-based compounds in wineries and cellars [88].

### 1.2.3. Regional cork institutions

There are two basic cork institutions in Catalonia; the Catalan Cork Institute (ICSuro) [12] and the Association of Cork Companies of Catalonia (AECORK) [13]:

- ICsuro is a public organisation and a type of consortium created in 1991 by Royal Decree 208/1991 (Official Journal of the Catalan Government 1509), established by the Catalan Government. Its main activities are (a) promoting and controlling quality standardisation of cork products, (b) research and development of the cork sector, (c) training internally and externally, and (d) promoting the Catalan cork sector at conferences and seminars [12].
- AECORK, was created in 1977 and currently brings together about 70 companies, representing about 95% of cork manufacturers in Catalonia. The activities of this organisation are mainly (a) to offer specialised, technical and analytical services to cork companies, (b) to collaborate in the official processes of standardisation of products, and (c) to coordinate the cork industry's lines of research [13].

## 1.3. Justification of the dissertation

The development of strategies towards sustainability is fundamental in the current context of societal development. Cork is a natural, renewable and local raw material which with correct management could contribute positively to different environmental services: the preservation of forest systems, the regulation of hydrology and the conservation of biodiversity. In addition to all of this, the cork industry is concerned about the impact of their activities and would like to reduce their current impact in the near future in order to improve their systems from the perspective of cleaner production. At the moment, the cork sector in Catalonia is not provided with quality data about the potential impact of their activities; and future environmental strategic decisions require an exhaustive approach to the whole system.

This dissertation is motivated by the following facts:

- The study of a complex system such as the cork sector **requires an approach from the IE perspective,** including an analysis of inputs and outputs throughout the systems, taking into account a **life cycle thinking** perspective. Furthermore, **environmental prevention strategies** could prove interesting**.**
- It is elemental to analyse the **cork sector as a whole**, but also divided into **individual parts**. This approach will give criteria focussed on the **improvement** of the **global** sector, but also on the improvement of **individual** subsectors.
- The present **lack of environmental data on the cork sector** is a clear motivation that justifies carrying out this investigation. There are no specific datasets about cork as a forestry raw material, or about the main cork products.
- **Previously**, there have been **very few studies evaluating** the potential environmental impacts of **cork sector, or any cork product**. Bibliographical research indicated that mainly natural cork stoppers had been evaluated: *Evaluation of the environmental impacts of Cork Stoppers versus Aluminium and Plastic Closures* requested by *Amorim,* the largest cork oak produced in 2008 [89], or the master thesis dissertation of *Avaliação do ciclo de vida da rolha de cortiça natural* [90], or *Life cycle assessment Of A Single-piece Natural Cork Stopper For Oenological Use* [91]. However, these studies only focused on one product and only feed from data of one specific industry.
- This current research evaluates the sector as a unique system, avoiding particular or individual case studies. This **scope** means that **average results of the sector** will be obtained for a given territory and a given time, avoiding particular cases studies. Besides, **LCA methodology** has been widely used to assess the environmental impacts associated with many industrial sectors in Catalonia but **not so far in the cork sector**. This then supposes an opportunity to implement this approach on this sector for the first time.

- Another important aspect that must be considered is the fact that the cork sector and more specifically the production of stoppers are a very important product in our country as it is related to the **important production of wine and cava**. Therefore, providing data of the impact of the stoppers will provide information for these producers. Specifically, in the future, some cork stopper producers could decide to certify the **carbon footprint** of their products, this present study would provide a first approximation for such cork stoppers certification.
- **Economical, social and environmental issues** are basic criteria for any future society to advance towards sustainability. At the moment, the cork sector can offer economic and social data about their products, but not environmental data. These last data would be necessary in order to differentiate their products from those of their competitors. This is for example, the case of natural cork stoppers that currently face strong competition from screw caps and plastic closures. **The stronger environmental performance must be an added value of the cork products** that is currently often omitted.
- **The predisposal of the cork sector to environmental issues** presents an excellent opportunity to design and plan for future challenges from both the sectorial and individual perspective. In particular, **ecodesign** methodology could be a strategy implemented to ensure that cork products become even better from an ecological viewpoint. Also, **ecoinnovation** in the sector is essential to progress towards greening production.
- One special motivation of particular relevance nowadays in the present dissertation is the role of cork oak and cork extraction as we face **climate change**. A global **estimation of carbon dioxide balance** will be carried out in order to evaluate the contribution of the cork sector in this aspect.

In the chapters that follow (3-7) raw cork slab extraction and most representative cork products in Catalonia will be assessed from an environmental perspective. The selected products and the reasons are:

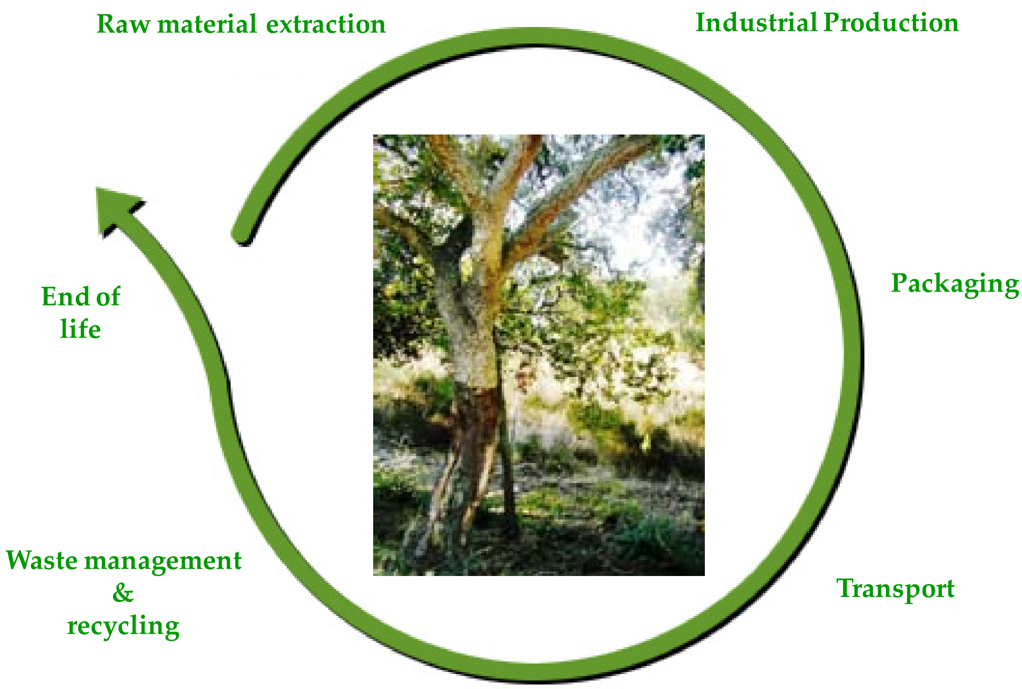
1) Cork slabs without any treatment direct from the forest; because this is the raw material for the whole industry.
2) Natural cork stoppers; because this is the most valuable product of the cork sector. Catalonia produces 10% of the natural cork stoppers worldwide (1,400 million natural cork stoppers each year) [20].
3) Cork granulate (both white and black varieties); because this is the basis for the production of all agglomerated products.
4) Champagne cork stoppers; because this is the most representative product of cork sector in Catalonia, as more than 60% of the champagne cork stoppers produced in the world are manufactured in this region (1,300 million champagne stoppers each year) [20].

## 1.4. Objectives of the dissertation

The main objective of this dissertation is **to assess the cork sector from an environmental perspective**, **through the study of its subsectors**. The investigation will be done by analysing the following systems: the cork oak forest and cork extraction, the natural cork stopper, cork granulates and the champagne cork stopper because they are the most representative.

In order to achieve this main objective, the following goals are outlined:

1. To apply the LCA methodology to the cork sector.
    - To assess a raw material extracted from a tree which has a useful life of about 200 years.
    - To adapt the methodology to a very traditional sector with small and medium enterprises.
2. To generate inventories of cork extraction and the production of different cork products for future LCA case studies and databases.
3. To evaluate the environmental impacts associated with cork oak forest management, and especially those associated with cork extraction.
4. To quantify and assess environmentally the production of natural cork stoppers in Catalonia by means of an analysis of its stages and operations.
5. To quantify and assess environmentally the production of cork granulates in Catalonia by means of an analysis of its stages and operations.
6. To quantify and assess environmentally the production of champagne cork stoppers in Catalonia by means of an analysis of its stages and operations.
7. To analyse environmentally the transport currently used in the cork sector.
8. To carry out a global carbon dioxide balance of the cork sector, considering the fixation rates of the forests and the emissions generated during forestry and industry activities.
9. To investigate the cork sector in Catalonia as a system integrating its subsystems from an IE perspective.
10. To determine the weaknesses of the sector and to propose actions to improve the current sector and subsectors from a cleaner production perspective.




# Chapter 2

# METHODOLOGY

**Chapter 2** presents an overview of the dissertation's methodological aspects. First, the sustainable assessment tool *"life cycle assessment (LCA)"* will be introduced briefly by describing its main phases and its particular aspects. Subsequently, the systems under study will be presented schematically focusing on their interconnection. Finally, all the aspects related to fieldwork and data collection processes will be detailed. It will be explained how the crude data was obtained, how inventories were calculated and how the impact assessment was performed.

This chapter is structured as follows:

- Life cycle assessment methodology.
- The cork sector and environmental studies.
- Overview of system and subsystems under study.
- Fieldwork: data collection processes.

# 2. Methodology

A sustainable assessment tool is a systematic process designed to identify, analyse and evaluate the environmental, social and economic consequences of a product, service or system. Many tools and indicators for assessing and benchmarking the sustainability of systems have been developed [92, 93]. In fact, there are an endless number of methodological tools that approximate sustainability from different perspectives and with different scopes. Table 2.1 presents some examples of sustainable assessment tools, but others methodologies can be found.

**Table 2.1. Sustainable assessment tools available: representative examples.** ***Sources: [92, 94-108].***

| Abbreviator | Name | Abbreviator | Name |
|---|---|---|---|
| CBA | Cost-benefit analysis | LCCA | Life cycle cost analysis |
| CM | Checklist method | LCECA | Life cycle environmental cost analysis |
| DMC | Direct material consumption | LCWE | Life cycle working environment |
| DMI | Direct material input | MEFA | Material and energy flow analysis |
| EA | Energy analysis | MFA | Material flow accounting |
| EF | Ecological footprint | MFCA | Material flow cost accounting |
| EIA | Environmental impact assessment | MIPS | Material intensity per unit service |
| ERA | Environmental risk assessment | SEA | Strategic environmental assessment |
| IOA | Input-Output analysis | SFA | Substance flow analysis |
| LCA | Life cycle assessment | SLCA | Social life cycle assessment |
| LCC | Life cycle costing | TMR | Total material requirement |

Part II (Chapters 3 to 6) and III (Chapter 7) are based on a specific sustainability assessment tool: the life cycle assessment (LCA). It is an analytical tool which can usefully assess the potential environmental impacts and resources used throughout a product, service or system life cycle from raw material acquisition through to production use and disposal [92]. LCA has been found to be the most appropriate methodology approach, or tool, to quantify and environmentally assess the cork sector because of the high international acceptance of the methodology, the grade of implantation in many studies and because several ISO standards [109-113] have been developed to streamline the methodology by providing a framework, terminology and to help with methodological choices.

## 2.1. Life cycle assessment

The *life cycle* concept started to develop at the end of the 60s, but it was in the 80s, when the life cycle assessment (LCA) awoke scientific interest and that its use became more widely extended. This was manifested in the fact that some institutions developed the initial methods for the aggregation of substances into *impact categories*. The institutions of reference that started to develop the methodology were the *Swiss Federal Laboratories for Materials Testing and Research* (EMPA), the *Swiss Agency for the Environment, Forests and Landscape* (BUWAL) and the *Institute of Environmental Sciences* (CML) in Leiden [114]. The use of LCA was generalised later in the 90s because of the decisive publication of handbooks, guides [115] and the performance of the first studies [114, 116].

The *Society of Environmental Toxicology and Chemistry* (SETAC) defined LCA as [117]:

> *"An objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal".*

In 1993 the ISO (International Standardisation Organisation) started to develop [109] and define LCA as :

> *"LCA is the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product[1] system throughout its life cycle".*

LCA is an environmental accounting and management approach that takes into account all the aspects of resource use and environmental releases associated with an industrial system from cradle to grave [47]. Specifically, it is a holistic outlook of environmental interactions that covers a range of activities, from the initial raw material extraction from the Earth, the production, distribution, use, reuse, and final disposal of a product, service or activity [3] (figure 2.1).

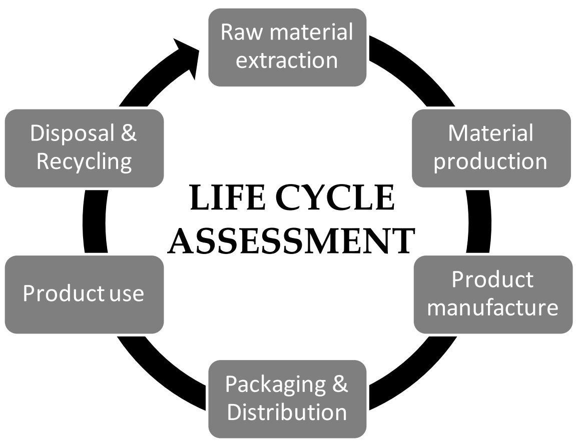



**Figure 2.1. Life cycle diagram of a product.**

[1] The ISO 14040 considers the term "product" to include services.

LCA can support in (a) identifying opportunities to improve the environmental performance of products at various points in their life cycle, (b) informing decision-makers in industry, government or non-government organisations, (c) selecting of relevant indicators of environmental performance, including measurement techniques, and (d) marketing: implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration [109].

According to ISO 14040 [109] and [118-120], the evaluation framework most commonly applied in LCA involves the following phases: (a) definition of goal and scope, (b) inventory analysis, (c) impact assessment, and (d) interpretation. LCA is an iterative process, which can be followed in different rounds achieving increasing levels of detail, and consequently the four phases are not followed simply one after the other. The methodology is often described at the product scale but fewer applications have been performed at different levels from a micro to a macro scale. The general framework of LCA can be observed in figure 2.2.

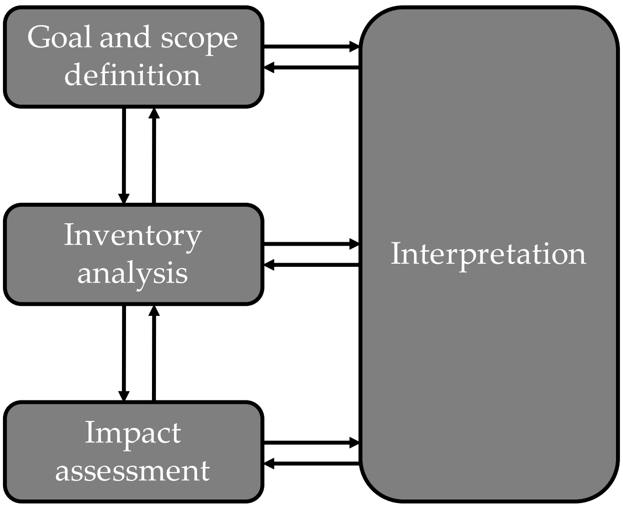



**Figure 2.2. Phases of an LCA.** ***Source: [109].***

Many software packages, databases and impact methods have been created and extended to facilitate the realisation of LCA studies, but the method is still under development. Nowadays, several international initiatives are ongoing to help build a consensus and provide recommendations, including the *Life Cycle Initiative* [121] of the United Nations Environment Programme (UNEP) [122] and the Society of Environmental Toxicology and Chemistry (SETAC) [123] that would enable users around the world to put life cycle thinking into effective practice; or the *European Reference Life Cycle Database* (ELCD) [124] and the *International Reference Life Cycle Data System* (ILCD) [125] of the European Commission [126].

There is a consensus in the scientific community about LCA being one of the best tools for evaluating environmental burdens associated with products and services [3, 114, 127]. Many works can be found using this environmental tool [128-133]. The following subsections introduce and describe each phase of the LCA.

### 2.1.1. Definition of goal and scope

Definition of goal and scope is the first phase of an LCA study, where purposes and intentions must be outlined noting the reasons for carrying out the study, the intended audience and whether the wished-for results are used in comparative assertions. The scope should be defined to ensure that the grade of detail of the study is compatible and sufficient to address the proposed goal. The scope includes (a) the description of the system under study, (b) its functions, (c) the functional unit, (d) the system boundaries, (e) the allocation procedure rules, (f) the methodology of impact assessment and the selected impact categories, (g) data requirements, (h) assumptions established, and, other requirements [110]. All these aspects are important and relevant, but the functional unit, the system boundaries and allocation are often the most widely discussed:

- The *functional unit* (FU) is a key element of LCA which has to be clearly defined and it refers to a measure of the function of the system under study and it provides a reference to which the inputs and outputs can be associated. It is essential to ensure the comparability between similar LCA studies.
- The *system boundaries* delimit the unit processes that are going to be included in the system. Defining system boundaries is partly based on choices that should be detailed and justified in order to provide confidence in the study. The system boundaries should notice which stages, unit processes and flows are to be considered in the study.
- *Allocation procedure* is a practice to distribute environmental burdens among products or processes. Different methodological approaches can be found, but the ISO 14041 [110] indicates that system expansion including the functions of co-products is preferred to dividing environmental burdens among systems [134]. However, cut-off criteria must often be used to simplify the complexity of the systems: especially for multifunction systems and open-loop recycling systems [135, 136]. Cut-off rules should be clearly understood and described, but they are fundamental to avoid infinite interconnected systems. The environmental burdens of multifunction systems can be divided up according to different factors such as economic or mass balance. Allocation is one of the most controversial topics in LCA methodology [134].

### 2.1.2. Inventory analysis

The inventory analysis phase, or *life cycle inventory* (LCI) is the phase where all the data related to the study is collected. The inventory analysis identifies and quantifies all the inputs and outputs of the system under study during its life cycle: raw materials and energy consumption, co-products and by-products generated, solid wastes and those released into the air, water or soil. the inventory analysis is generally the phase that requires most time, especially when local quality data are collected. LCI represents the first basic results of an LCA study.

Inventory data is typically collected by means of survey questionnaires, which after being validated, are transformed and adapted to the FU, and can often be presented in tables which facilitate the structuring and storage of the information. An example of these tables can be observed in table 2.2.

**Table 2.2. Example of an inventory table for an LCA study.**

| INPUTS | | | |
|---|---|---|---|
| **From the technosphere** | | **From nature** | |
| *Type* | *Quantity (units)* | *Type* | *Quantity (units)* |
| Materials | kg/UF | Water | l/UF |
| Fuels | kg/UF (MJ/UF) | Minerals | kg/UF |
| Energy | MJ/UF | Biomass | kg/UF |
| Transports | km/UF | | |
| Water (l) | | | |
| **OUTPUTS** | | | |
| **To the technosphere** | | **To nature** | |
| *Type* | *Quantity (units)* | *Type* | *Quantity (units)* |
| Product | Units/UF (kg/UF) | Emissions to air | kg/UF |
| Co-products | Units/UF (kg/UF) | Emissions to water | kg/UF |
| By-products | Units/UF (kg/UF) | Emissions to soil | kg/UF |
| Wastes for treatment | kg/UF | | |

## 2.1.3. Impact assessment

The impact assessment phase, or *life cycle impact assessment (LCIA)*, is expected to evaluate the potential environmental impacts transforming hundreds of inventory inputs and outputs into a few impact categories, thus attempting to understand these impacts. LCIA results determine the relative importance of each item on the inventory and add a set of indicators, or a single global indicator. In addition, LCIA is very useful to identify which processes of the system under study contribute most to those potential environmental impacts, and allow for a comparison of products and services. In fact, LCIA analyses the potential environmental effects of the system under study on human health, ecosystems and natural resources [137] providing information for the interpretation phase.

Some of the LCIA elements are mandatory while others are optional [111], as can be observed in Figure 2.3. During the initial goal and scope phase the impact categories to be analysed must be selected and clearly indicated. Following this, the classification and characterisation steps are mandatory, while normalisation is optional:

- Classification corresponds to a process in which all the environmental interventions identified in the inventory (inputs and outputs) are grouped in different impact categories or indicators, according to the environmental effects they are expected to contribute. For example, $SO_2$,

$NO_x$, $NH_x$, etc., emissions are classified in the Eutrophication Potential category.

- Characterisation is the calculation of impact category indicators using specific characterisation factors that are available to practitioners in literature, databases, and LCA support tools [137]. Characterisation factors are factors derived from characterisation model which allows all substances that contribute to this category to be reduced to a single reference substance [138]. For example, the classified $SO_2$, $NO_x$, $NH_x$, etc., emissions are reduced to an equivalent substance: $SO_2$ equivalent.
- Normalisation is the calculation of category indicator results relative to reference values. The objective of this step is to place LCIA indicator results into a broader context and to adjust the results with common dimensions. The advantage is that by using different criteria, the impact categories can be transformed into a numerical score of environmental impact, thus making it easier to make decisions, but also losing certain information. The normalisation step by grouping and weighting can approximate the results in particular areas of protection such as human health or ecosystems. However, limitations are important, and for this reason this practice is optional and often LCA studies avoid carrying out this step.
    - *Grouping* is a semi-quantitative process that involves sorting and/or ranking results across impact categories.
    - *Weighting* refers to using numerical factors based on value choices to facilitate comparison across impact category indicators.

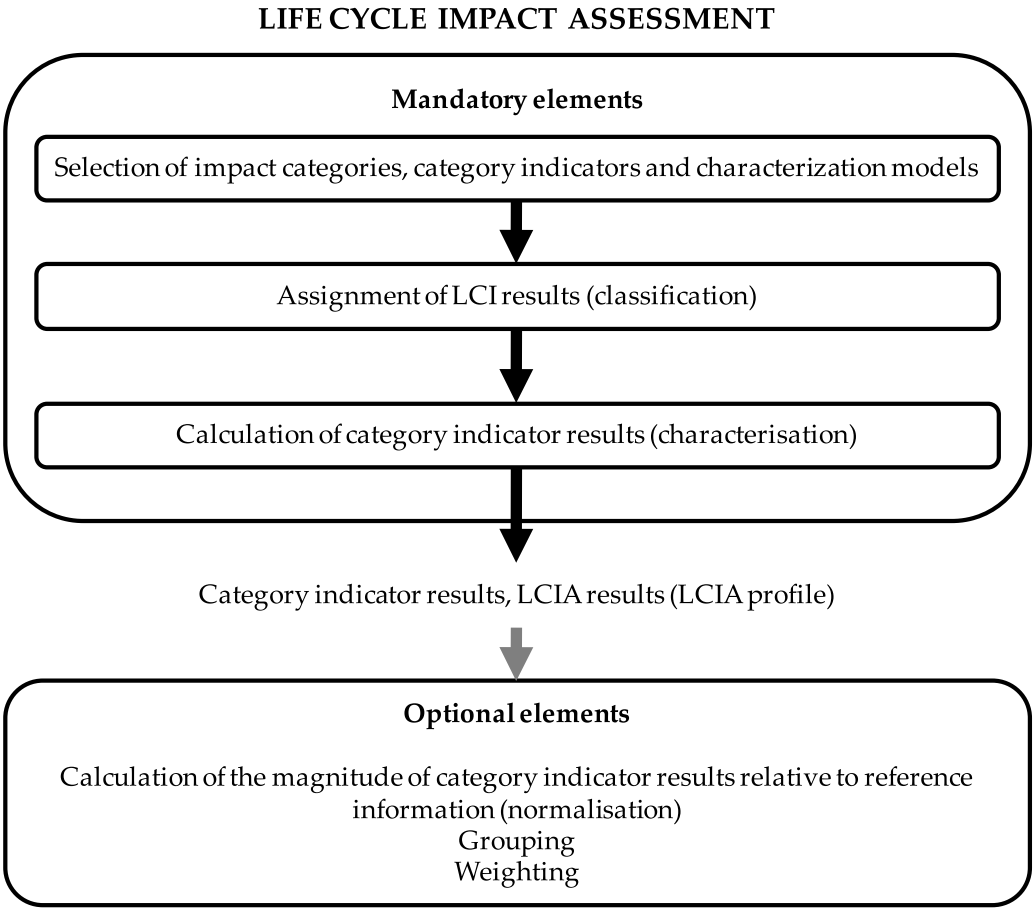



**Figure 2.3. Elements of the LCIA phases of an LCA.** ***Source: [109].***

## 2.1.4. Interpretation

Interpretation is the phase of LCA in which the findings from the inventory analysis and the impact assessment are considered together. The interpretation phase should indicate the consistency of the results according to all the aspects defined during the goal definition and scope phase. In this last phase of LCA, it is necessary to outline conclusions, explain limitations that have occurred, and provide recommendations. The interpretation phase may involve the iterative process of reviewing and revising the scope of the LCA, as well as the quality of the data collected.

## 2.2. The cork sector and environmental studies

The cork sector is now becoming a cluster in Catalonia: a geographical concentration of companies, institutions and agents involved in the cork market. One of its principal strategies in the future is to advance towards sustainability. The first step for accomplishing this purpose is obtain quality data of the three sustainability pillars: economy, society and environment. Social and economic data is now obtainable, but very few environmental data is yet available. Table 2.3 reports some of the environmental studies carried out on cork sector. All of them have been done only considering one individual company, and none of them has been published in peer-review journals. Moreover, none of them has focussed on the Catalan cork sector. Each piece of research has its own scope, system, considerations, environmental assessment, impact categories, and so on. Consequently, comparison among all these studies is complex.

**Table 2.3. Previous environmental studies of the cork sector.**

| Author | Title | Year | Ref. |
|---|---|---|---|
| Pricewaterhouse-Coopers | Evaluation of the environmental impacts of Cork Stoppers versus Aluminium and Plastic Closures | 2008 | [89] |
| Moreira RP. | Avaliação do ciclo de vida da rolha de cortiça natural (master thesis) | 2009 | [90] |
| Ecobilancio | Life cycle assessment Of A Single-piece Natural Cork Stopper For Oenological Use | 2004 | [91] |
| Ecobilancio | Valutazione del ciclo di vita di un tappo ad uso enologico in sughero agglomerato | 2004 | [139] |
| Cairn environment | Carbon appraisal of the different methods used for closing still wines | 2007 | [140] |

In this present dissertation, the cork sector is analysed using LCA methodology for the first time in Catalonia. Results will be representative of the sector as a whole and not of a particular enterprise because of the scope of the research. The goal and scope of each subsystem will be described for everyone to see in chapters 3-7. In each case, the functional unit (FU), the functions of the subsystem, the system boundaries, the allocation procedure rules, and other aspects will be outlined. Comparison with other raw materials or products will be avoided because to achieve this purpose it would be necessary to assess those products in the same degree of detail as was carried out for the cork sector.

## 2.3. Overview of the system and subsystems under study

This section introduces the system under study and its main parts. The divisions were established at the beginning of the dissertation because it was found to be more appropriate to assess each subsystem separately in accordance with their differences. In fact, the cork sector system was firstly separated in two parts due to the different scope and approach: forestry cork subsystem and industrial cork subsystem. Then, the industrial subsystem was also fragmented into three subsystems: natural cork stopper production, champagne cork stopper production and granulate cork production. The general framework of the cork sector and how it is structured in this present dissertation can be seen in figure 2.4.

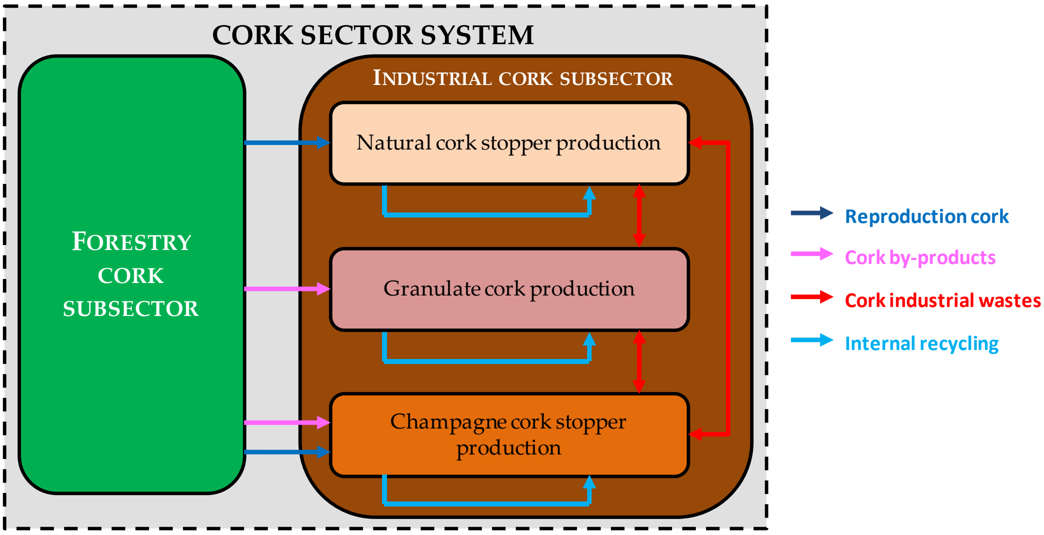



**Figure 2.4. The framework of the cork sector system and subsystems showing the main raw cork flows exchanged.**

All the subsystems in the cork sector are interrelated because there are transferences of cork flows from one subsystem to another. It is clear, that all raw cork materials originate in the forest to be later transported to industrial cork subsystems. As was explained in the introduction of the dissertation, different raw cork materials are generated in the forest: reproduction cork and cork by-products[2]. The reproduction cork that is the most useful and of better quality, is always intended for the production of natural cork stoppers that is the most economically valuable product made of cork. But, reproduction cork slabs with a thickness below 27 mm [64] are destined for champagne cork stopper production, specifically to produce the natural cork discs required to produce champagne cork stoppers as well as other technical stoppers. On the other site, cork by-products are always sent to produce cork granulate or to produce the granulated-

[2] *Cork by-products:* group of cork resources of low economic value composed by: virgin cork, second cork, virgin winter cork, fragments of reproduction cork and cork with defects.

agglomerated cork body of champagne cork stopper. Finally, different flows of cork industrial wastes are connected across the subsystems. For example, during the production of natural cork stoppers or discs, a large percentage of the cork becomes waste in this process and is then recycled into granulates. Furthermore, cork dust is generated during the production of natural cork stoppers, champagne cork stoppers and cork granulate. Cork dust can be used in the same subsystem or in another subsystem as a renewable source of energy. Nowadays, some of the interconnections among the systems take place frequently; while others are just starting to be implemented in the larger companies. Other connections may exist in the future within the cork sector or with other economic sectors.

## 2.4. Fieldwork: data collection processes

During the dissertation different fieldwork has been carried out to obtain all the data on the cork sector. One of the main interests of the thesis is the evaluation of the whole system, subsystems, production stages and even production operations of the cork sector; for this reason, it has been completely fundamental to collect a great deal of local data. As will be explained in next subsections, to obtain these data was the part of the dissertation that required most effort in terms of time and work. An easier and simplified approximation of the cork sector could be done with something such as a black box system where inputs and outputs are analysed at a macro scale, but the results obtained would be less relevant and of less interest, making it impossible to assess what happened into the black box.

To carry out LCA with the disaggregation of the present study allows for the proposal of improvements to the subsystems from a cleaner production perspective. In fact, the data demanded for the industry system was at a very small scale: "*manipulation to manipulation*" in order to analyse all the aspects of production, but finally it was decided to increase the degree of detail to "*operation to operation*" in order to obtain more significant results. This means that two or three manipulations were aggregated into operations.

Most of the data were local, but general processes were used from Ecoinvent [141-143] that contains international industrial life cycle inventory data on energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste management services, and transport services [144]. The use of LCA databases has been important because it has saved a lot of time by not having to collect data from related systems. Also GaBi databases [145] was used for comparison, but finally all the LCIA was calculated using local data and general Ecoinvent processes. Table 2.4 presents the origin of the different used data.

**Table 2.4. Summary of data sources.**

| Type of data | Component | Reference document |
|---|---|---|
| Local | Production processes<br>Raw material consumption<br>Auxiliary materials consumption<br>Energy consumption<br>Water consumption<br>Waste management | Reported from fieldwork and data collection process |
| General | Transports<br>Raw materials<br>Energy<br>Waste management | Ecoinvent v.1.2, v2.1, v2.2 [143, 144] |

## 2.4.1. Inventory of data collection

Usually the collection of data is the part of an environmental study that involves most work and time; and the cork sector was no exception. The process started with an initial meeting of all the actors involved in each subsector. It was in the framework of a four-year CENIT-DEMETER project (2008-2011): "*Desarrollo de Estrategias y Métodos vitícolas y Enológicos frente al cambio climático*", and its sub-activity 7.2 that was associated to environmental evaluation of the cork sector by means of LCA. In this meeting, the four cork sector subsystems were identified as the potential parts to be studied. According to this, four different collection data processes were to be carried out in parallel; one for each subsystem. Consequently, four different specific questionnaires had to be developed (Table 2.5).

The name and details of the industries participating in the project was confidential, and for this reason results will be only expressed in sectorial averages.

**Table 2.5. Specific questionnaires for data collection.**

| Name | Number of initial experimental samples | Number of final experimental samples |
|---|---|---|
| Cork oak forest management questionnaire | 1 | 5 |
| Natural cork stopper questionnaire | 5 | 4 |
| Cork granulate questionnaire | 3 | 3 |
| Champagne cork stopper questionnaire | 5 | 5 |

At the beginning, the selection of experimental samples was directly associated to the CENIT-DEMETER project. For this reason, only one single cork oak exploitation was planned to be studied, but over time four new exploitations were incorporated into the study, improving the quality of the results. Unfortunately, during the collection data process, a natural cork stopper industry closed down and consequently the number of experimental samples was reduced from 5 to 4. Annex I presents two examples of questionnaire models, including all the tables and information demanded.

The inventory data collection process is presented schematically in figure 2.5. It can be stated that the process started in a meeting of all the actors involved in the process, where the sector was introduced. A standardized work protocol, known as PNT, was established at the beginning of the project in order to regulate communication among all the stakeholders.

Following this, fieldwork was carried out in all the cork subsystems. During this stage, natural cork stopper industries, champagne cork stopper industries, cork granulate industries and cork oak forest exploitation were audited. Subsequently, a *questionnaire model* for each subsystem was developed according to experts from the cork companies. Before being sent out, the questionnaires were tested and checked. During the whole data collection process, companies, forestry owners and ICSuro [12] were always given guidance to help them give the required and correct information. Before obtaining the final individual inventory of each company, several revisions and improvements were required. Finally, the completed **individual inventory** was verified and closed (Figure 2.5).

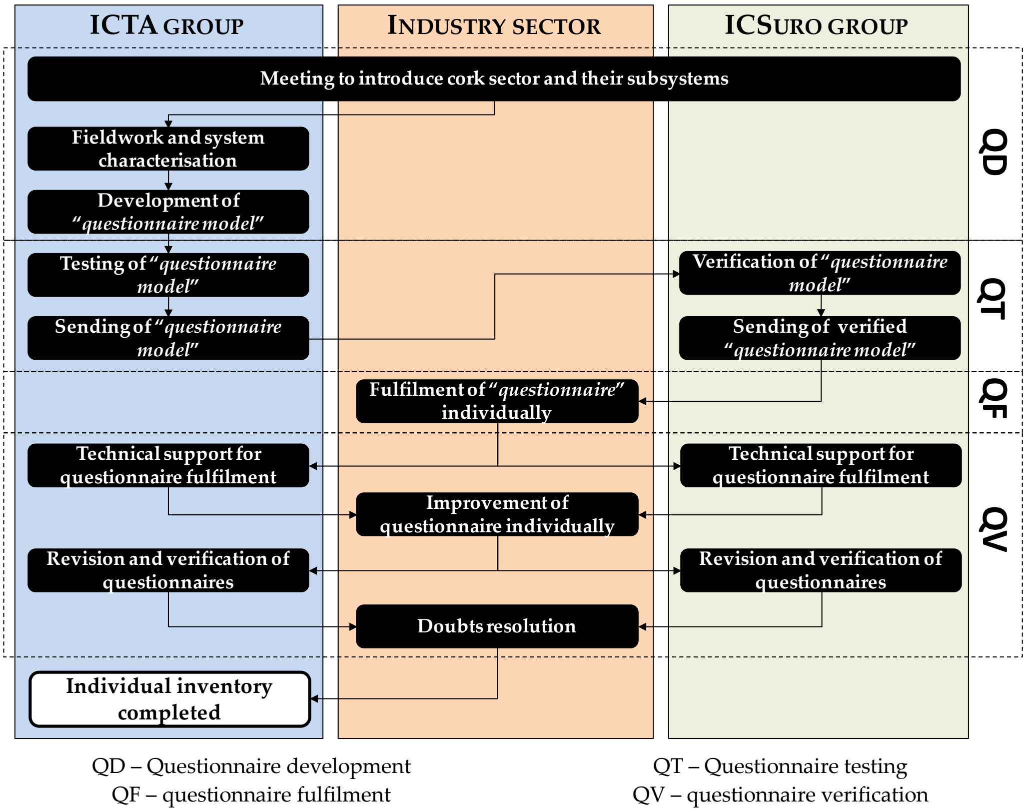



**Figure 2.5. Overview of inventory data collection process for industry.**

The collection of data was similar for the four subsystems. Only a few differences occurred with the forestry subsystem due to their different approach. Specifically, the difference was that technical support, revision and verification was also carried out by CFC [66].

Each *questionnaire model* was adapted to each subsystem. They all included a specific table for each individual manipulation, involving a lot of tables. These questionnaires covered the entire life cycle of each subsystem from the raw material to the distribution of the products and management of the wastes generated. More about each questionnaire will be explained in the methodology sections in Chapters 3-6, and in Annex I. Each *questionnaire model* was structured into several *answer sheets* (table 2.6).

**Table 2.6. Information demanded in specific questionnaires.**

| Answer sheet | Description |
|---|---|
| Basic information | To fill out the questionnaire where vocabulary was described |
| General information | General information of the industry/forest exploitation, including contact data, industry/forest characteristics, yearly production, documents available, and so on. |
| Answer sheets (production) | Several answer sheets for each production stage, including an individual table for each manipulation |
| Answer sheets (non-production) | Several answer sheets for particular aspects not directly related to a production stage: auxiliary materials, energy sources, water and wastewater management, waste management and so on. |

After the individual inventories were obtained they needed to be homogenised because the flexibility of the questionnaires allowed for information to be given in different ways. Subsequently, crude data were adapted to the FU established in each subsystem. Besides this, as the scope of the dissertation was to assess the sector and not only individual factories, calculations and averages should be performed. However, accounting with reference data of more than one company added complexity to the study, but does give significant reliability to the results of the sector. Moreover, it allows for a comparison between individual results and the average. The process is illustrated schematically in Figure 2.6.

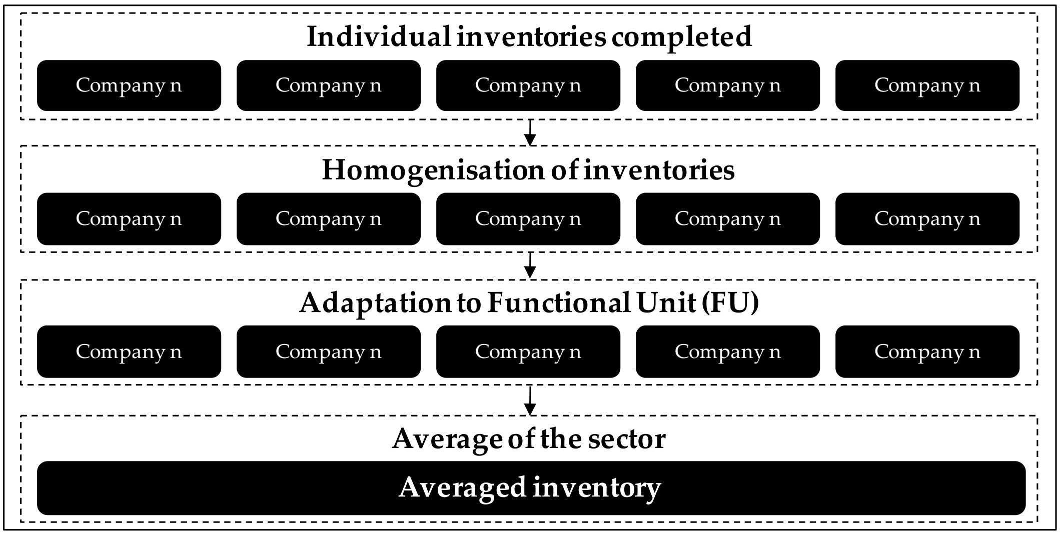



**Figure 2.6. Overview of sector average *versus* industry calculation.**

## 2.4.2. Life Cycle Impact Assessment (LCIA)

The LCIA was performed according to the averaged out inventory of the sector and following ISO 14040 [109, 146] requirements. The three mandatory elements specified by ISO 14040 were followed: selection of categories, classification and characterisation. Otherwise, optional items normalisation, grouping and weighting were excluded to avoid subjectivity and to obtain the same mid-point impact categories [127], and because there are no specific values for Mediterranean region. The characterisation method used was the CML 2 (2001) [119, 138] which is based on environmental impact categories' intermediate effect. The method had been developed by the Institute of Environmental Sciences at the University of Leiden (The Netherlands) and is widely used worldwide [95, 147]. Table 2.7 reports the mid-point impact categories considered:

**Table 2.7. Mid-point impact categories considered during the dissertation.** ***Source: [138, 148].***

| Short name | Name | Units | Description |
|---|---|---|---|
| ADP | Abiotic depletion potential | kg Sb eq. | It is concerned with the protection of human welfare, human health and ecosystem health. It is related to the extraction of minerals and fossil fuels due to inputs into the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels based on concentration reserves and the rate of de-accumulation. |
| GWP | Global warming potential | kg $CO_2$ eq. | It can result in adverse affects upon ecosystem health, human health and material welfare. Climate change is related to emissions of greenhouse gases into air. The characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterisation factors. Factors are expressed as for time horizon of 100 years. |
| AP | Acidification potential | kg $SO_2$ eq. | Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). AP factor emissions into the air are calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances. |
| EP | Eutrophication potential | kg $PO_4^{3-}$ eq. | It includes all impacts due to excessive levels of macro-nutrients in the environment caused by emissions of nutrients into the air, water and soil. It is based on the stoichiometric procedure of Heijungs (1992). Fate and exposure is not included. |
| ODP | Ozone layer depletion | kg CFC eq. | Because of stratospheric ozone depletion, a larger fraction of UV-B radiation reaches the earth's surface. This can have harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials. This category is output-related and at global scale. The characterisation model is developed by the World Meteorological Organisation (WMO) and defines ozone depletion potential of different gasses. |
| POCP | Photochemical ozone creation potential | kg $C_2H_4$ eq. | It considers the formation of reactive substances (mainly ozone) which are injurious to human health and ecosystems and which also may damage crops. This problem is also connected to "summer smog". Winter smog is outside the scope of this category. It is calculated with the UNECE Trajectory model. |
| HTP | Human toxicity potential | kg 1.4 DB eq. | It concerns the effects of toxic substances on the human environment. Health risks of exposure in the working environment are not included. Characterisation factors are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. |
| TETP | Terrestric Ecotoxicity potential | kg 1.4 DB eq. | It refers to impacts of toxic substances on terrestrial ecosystems, as a result of emissions of toxic substances into the air, water and soil. It is calculated with USES-LCA, describing fate, exposure and effects of toxic substances. |
| FAETP | Freshwater aquatic Ecotoxicity potential | kg 1.4 DB eq. | It refers to impact on fresh water ecosystems, as a result of emissions of toxic substances into to the air, water and soil. It is calculated with USES-LCA, describing fate, exposure and effects of toxic substances. |
| MAETP | Marine aquatic Ecotoxicity potential | kg 1.4 DB eq. | It refers to impacts of toxic substances on marine ecosystems, as a result of emissions of toxic substances into the air, water and soil. It is calculated with USES-LCA, describing fate, exposure and effects of toxic substances. |
| RAD | Radioactive Radiation | Daly | It covers the impacts arising from releases of radioactive substances as well as direct exposure to radiation, in building materials for example. Exposure to ionising radiation is harmful to both human being and animals. Areas of protection are human health, natural environment and natural resources. |

Nowadays, there are many computer programs that help with the realisation of LCA dissertations and which incorporate databases of various economic processes. Software packages introduce inventory data and model the stages of the product or service. In this dissertation Gabi software was used, always in the newest version available [145]. It was developed by the Institute for Polymer Testing and Polymer Science (IKP) of the University of Stuttgart and PE Europe GmbH in Germany.

# PART II

## Environmental assessment of cork oak forestry management in Catalonia

Chapter 3: Environmental analysis of raw cork extraction in cork oak forests in Southern Europe (Catalonia – Spain)

# Chapter 3

# ENVIRONMENTAL ANALYSIS OF RAW CORK EXTRACTION IN CORK OAK FORESTS IN SOUTHERN EUROPE (CATALONIA – SPAIN)

# 3. Environmental analysis of raw cork extraction in cork oak forests in Southern Europe (Catalonia – Spain)

This chapter is based on the following paper:

- **Rives, J., Fernandez-Rodriguez, I., Rieradevall, J., Gabarrell, X. Environmental analysis of the raw cork extraction in cork oak forests in Southern Europe (Catalonia – Spain). Submitted on May 2011 to *Journal of Environmental Management*.**

## Abstract

Cork oak grows endemically in a narrow region bordering the western Mediterranean, and especially in the Iberian Peninsula. The importance of cork agro-forestry systems lies in the fact that a natural and renewable raw material – cork – can be extracted sustainably without endangering the tree or affecting biodiversity. This ecomaterial is useful for making different types of products.

This paper describes an environmental analysis of the extraction of raw cork in cork oak forests in Catalonia, using data from five representative local forest exploitations. The evaluation was carried out using life cycle assessment (LCA) methodology, and all the forestry management required to obtain a tonne of raw cork was included. The aim of the study was to find out more about the impacts caused by cork extraction and determine the carbon dioxide balance of these forestry systems, with a tree lifespan of about 200 years, to analyse the possibilities of improving them and to provide environmental data for future LCA studies.

Results indicate that raw cork is a useful natural material for producing multiple products with very low emissions. During the life cycle extraction of cork in Catalonia, 0.2 kg of $CO_2$ eq. was emitted per kg of raw cork extracted. Moreover, cork cannot be extracted without the tree, which will be fixing carbon dioxide throughout its technological useful life (200 years), despite the fact that the bark is removed periodically: every 13-14 years. If the emission from extraction and the carbon contained in the products is also discounted, the carbon dioxide balance indicates that 18 kg of $CO_2$ are fixed per kg of raw cork extracted. Therefore, cork is a natural, renewable and local material that can replace other non-renewable materials, at local level, to reduce the environmental impacts of products, and particularly to reduce their carbon footprint.

## Keywords

Agro-forestry system, carbon dioxide, climate change mitigation, cork, cork oak forest, life cycle assessment (LCA), Mediterranean.

## 3.1. Introduction

Cork oak (*Quercus suber L.*) is a characteristic species that is endemic to the forests of the western Mediterranean region. It can reach up to 20 m tall and live for several centuries, and can survive adverse conditions such as cutting, grazing, prolonged drought, fire, and so on. It has one feature that is extremely rare throughout the plant kingdom: an outer coat of insulation consisting of corky bark made of continuous layers of suberized cells, up to 20 cm thick, which may have evolved as an adaptation to fire [16] and to avoid water loss [149]. The bark of the cork oak is composed of dead cells with trapped air, whose walls contain large amounts of suberin that give cork very good gas and water insulation properties [150]. This cork bark is a valuable natural material for industry, that can be stripped off the trunk without endangering the tree [26]. In fact, cork bark is removed every 9-14 years, depending on the region where the forest is located, and the tree is able to add new layers of cork bark every year [151].

The cork oak grows from sea level to 2000 m, but with optimum growth occurring up to 600 m altitude, with mean annual precipitation of 600-800 mm, but it still survives in years with very low precipitation - under 400 mm [17]. It is very well adapted to the Mediterranean type of climate, with precipitation concentrated in late autumn and winter (October-March) and very little, if any, summer rain [15]. The optimum mean annual temperature is in the range 13-16ºC [28]. This species is very soil adaptable, with the exception of calcareous and limestone substrates. It can grow on poor and shallow soils with low nitrogen and organic matter content and it tolerates a pH range between 4.8 and 7.0. The cork oak occurs mainly in siliceous and sandy soil, and prefers deep, well-aerated and drained soils [17]. Cork extraction is a key factor determining post-fire cork oak survival [53].

Cork oak agro-forestry systems are a model of sustainability between human activity and natural resources [152, 153]. Besides cork, other potential products, such as wood, biomass, medical plants, mushrooms, honey, decorative shrubs, and so on, can be obtained, though in smaller quantities. Cork oak is the economically essential element in this multifunctional system because it is extracted in greater quantities and because it is the most valuable product and, consequently, the main source of income from these forests [39]. These forestry systems also contribute to different environmental services, such as carbon storage, hydrology regulation, the prevention of desertification, biodiversity preservation, and so on [16]. In addition, cork oak agro-systems provide other indirect services such as recreation opportunities for the public or ecotourism. Modern cork oak agro-forestry systems are not completely natural because they are the result of human activities over the centuries. Cork extraction contributes to the maintenance of an ecosystem of high ecological value that would probably disappear if it were not profitable [25].

Table 3.1 presents the area given over to cork oak and raw cork production by the principal producer countries. Cork oak now covers 2.27 million ha around the world and practically 300,000 t of raw cork are extracted annually. More than 55%

of the area and more than 82% of production are concentrated in the Iberian Peninsula [18]. In Portugal, the highest concentration of cork oak is found south of the river Tagus in the regions of Alentejo and the Tagus valley [17], while in Spain the cork oaks are concentrated in the south-western regions of Andalusia and Extremadura, and in Catalonia (north-eastern Spain), which have 116,000 ha where the cork oak species is present and 63,000 ha where it is dominant. This represents 12% of the area of Spain [68].

**Table 3.1. Worldwide cork oak area and raw cork production by country.** *Source: [18].*

| | Cork oak area (ha) | Cork oak area (%) | Raw cork extracted yearly (t) | Raw cork extracted yearly (%) |
|---|---|---|---|---|
| Portugal | 736,700 | 32.3 | 157,000 | 52.5 |
| Spain | 506,000 | 22.2 | 88,400 | 29.5 |
| Algeria | 414,000 | 18.2 | 15,000 | 5.0 |
| Morocco | 345,000 | 15.1 | 11,000 | 3.7 |
| France | 92,000 | 4.0 | 3,400 | 1.1 |
| Tunisia | 92,000 | 4.0 | 7,500 | 2.5 |
| Italy | 92,000 | 4.0 | 17,000 | 5.7 |
| **Worldwide** | **2,277,700** | **100** | **299,300** | **100** |

The purpose of this research was to quantify the environmental burdens related to cork extraction activities. To date, other environmental assessments related to wood applications have been carried out [132, 154-156], but very few cases concern cork products. In fact, most of these environmental assessments were performed by our group in a project carried out three years ago [157-159]. All the previous studies focused on improving industries, while current research tries to supply new local data for cork oak forestry activities that was not previously available. This environmental assessment will be of interest to all the agents involved in the cork sector because new data for a future LCA case study will be available regarding a system that provides a natural, renewable and local resource which can be used in multiple applications, such as building materials, cork stoppers, furniture, decoration, and so on.

## 3.2. Cork oak agro-forestry systems

Basically, cork oak agro-forestry systems can be divided into two differentiated models, neither of which is completely natural because they are the result of centuries of continuing objective-oriented management [17]:

1 – Silviculture model: cork oak woodlands, known as "*Montados*" in Portugal and "*Dehesas*" in south Spain, are the most representative landscape. This system has a relatively small number of trees per ha: 50-150, and it is associated with pasture for livestock grazing and agricultural crops. In these intensive types of system most of the trees are planted [41] and, due to the fact that they are normally located in the south of the Iberian Peninsula, with the subsequent climatic and environmental conditions, faster cork oak tree growth is caused, so extraction can be carried out every 9 years [67].

2 – Forest model: Cork oak forests represent a system where the cork oaks are grown in denser stands, with unevenly-aged trees. This system is the model established in Catalonia and an average of 400 productive cork oak trees might be found per ha [23]. The usual establishment of new cork oak trees is by natural regeneration, and the extraction rate is between 12 and 14 years. Catalan raw cork is generally of better quality due to the fact that the growth of the cortex is slower and extraction is more spaced out over time [20].

Both agro-forestry system models extract cork, but the first is more organised, as it includes planning and planting. The yield quantity of cork extracted is lower in the forest model - 150 kg/ha/year - while the silviculture model can be over 200 kg/ha/year [20].

### 3.2.1. Cork oak forests in Catalonia

This research was carried out in Catalonia because the development of the cork sector began in this region and a cork sector cluster is currently developing [21]. In 2007, the Catalan cork cluster comprised more than 85 companies and 1,200 workers, and turnover was 228 million euros [20]. At the moment, Catalonia can only extract 8-9 thousand t of raw cork annually: only 10% of the raw material required by Catalan industries. For this reason, large amounts of raw cork must be imported from southern Spain and Portugal.

Figure 3.1 schematically presents the cork oak tree cycle in Catalonia. After germination and initial growth of the tree, virgin cork extraction takes place when the perimeter of the tree at chest height is 65 cm, in accordance with Catalan law [56]. This happens when the tree is about 35-40 years old, but it can occur later, depending on the particular environmental conditions of the trees. After 13-14 years, cork is extracted for the second time and, every 13-14 years, the tree is harvested again, to obtain reproduction cork. An individual cork oak tree can survive for 250-350 years, but 200 years seems to be the limit for an industrially useful cork production [17] because of the loss of quantity and quality of cork after this period. In accordance with this, each tree could be harvested at least 12 times during its lifespan.

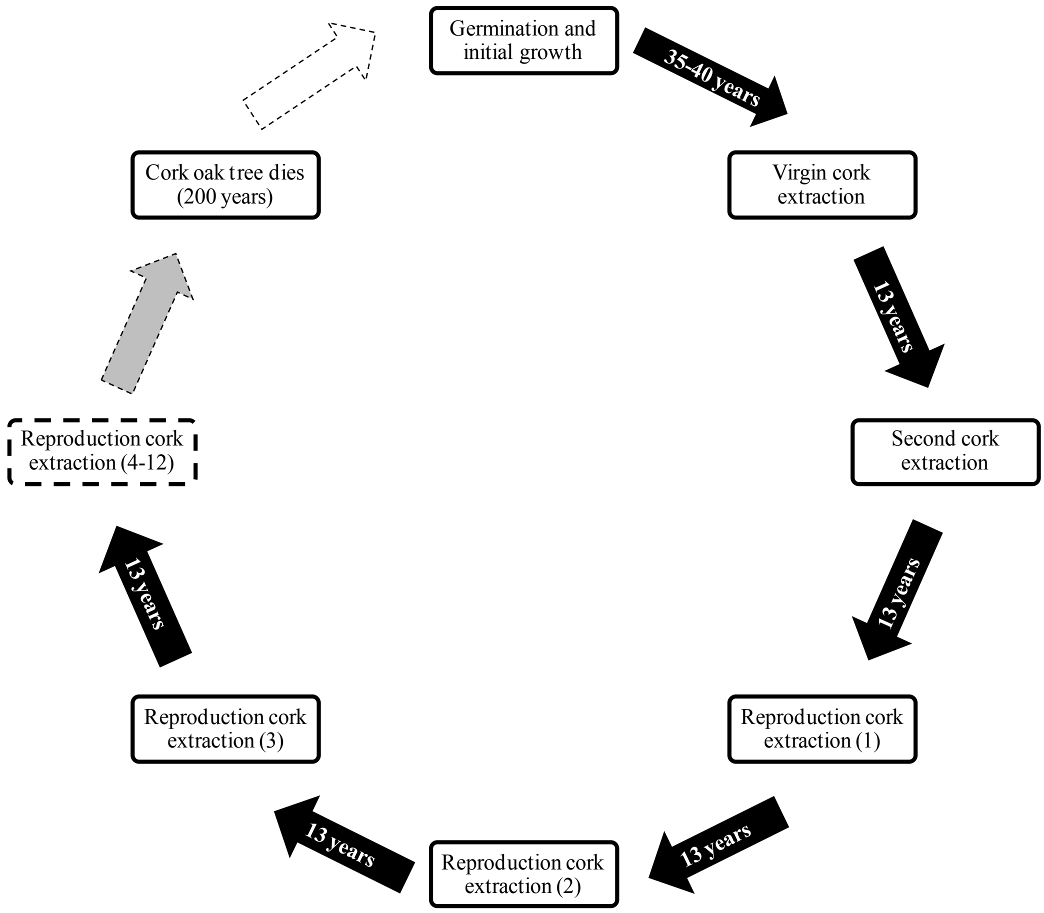



**Figure 3.1. Cork oak tree cycle in Catalonia.**

In Portugal and in southern Spain, where the silviculture model is established, the period of extraction is only every 9 years due to climatic and environmental conditions favouring faster growth [34, 41, 49, 53, 160, 161]. Portuguese forestry legislation prescribes that a minimum period of 9 years must elapse between any two consecutive cork bark extractions from the same tree, as reducing that period may have a negative impact on future yields from the tree or even lead to mortality [41].

In Catalonia, cork oak forests are basically private exploitations managed by an individual landowner, and each forest exploitation presents a particular forest structure: some exploitations are pure cork oak forest while other are mixed forests with pines or holm oaks [162]. Trees of different ages are found in the same area because this is fundamental to ensuring natural regeneration [25]. In Catalonia, pure cork oak forests could comprise about 700 trees per ha, of which 400 are cork productive while 300 are in the initial phases of growth and are intended for regeneration [23]. Cork oak forests are, by nature, heterogeneous systems.

Five different cork oak forest exploitations in Catalonia were selected for carrying out the environmental assessment. All of them are pure cork oak forests located in north-eastern Catalonia, between the Pyrenees and the Costa Brava. All are located near cork industries and they were chosen because there is available data reporting their activities and because they were found to be representative of cork oak forests in Catalonia. The landowners supplied the data about their management activities during recent years, and all this information was then verified by the Catalan Cork Institute and the Catalan Forestry Consortium. In addition, the Catalan Forestry Consortium confirmed technical data about cork oak forests in Catalonia. All the exploitations showed similar environmental conditions and microclimates. Their average annual precipitation ranged between 600 and 850 mm, their average annual temperature was about 15ºC, and their altitude above sea level ranged from 70 to 750 m.

Cork oak forests in Catalonia are being abandoned due to decreasing profitability [16]. Nowadays, it is estimated that 50% of Catalan cork oak forests are not managed in any way and, if exploitation of these forests begins, cork extraction in Catalonia could be doubled, and the risk of fires and soil erosion could be reduced [56, 163]. Cork oak forests in Catalonia were studied for this paper because environmental research on these systems could contribute to their preservation, because of the current availability of data, and because this agro-forestry system had not been yet been studied from a life-cycle perspective.

## 3.3. Methodology

Life cycle Assessment (LCA) [115, 164] is compiled from several interrelated components: scope and goal definition, inventory analysis, impact assessment and interpretation [118]. In this study, the methodological regulations in the ISO 14040:2006 standard have been adopted [109].

### 3.3.1. Scope and goal definition

The purpose of this research was to use LCA methodology to quantify and evaluate the environmental impacts related to all the forestry activities necessary to extract raw cork material. To date, other studies of the cork sector have been carried out by our group [157-159], but all of them focus on industrial systems. Forest management was excluded from the systems studied because there was then a lack of data and, because of their different approaches, it was found more appropriate to evaluate the cork oak forest system individually.

The results of this paper will quantify the total environmental emissions caused to obtain cork and determine which particular processes cause most pollution. Moreover, carbon dioxide balance will be determined according to a local fixation bibliographical reference [165]. The results will be of interest to the entire cork sector - specific institutions, producers and forest landowners - but also for future LCA studies and databases.

### 3.3.2. Functional Unit (FU)

The functional unit (FU) established in the study was a tonne of raw cork material. It was considered that 86% of the raw material corresponded to reproduction cork[3] constituting the raw material with the greatest economic

[3] Reproduction cork is the raw material obtained after stripping virgin and second cork. This resource is obtained after 60-65 years of tree growth in Catalonia and is mainly used to generate solid cork products,

value, and 14% corresponded to cork by-products[4] with lower added value. Cork by-products are an unavoidable and collateral consequence of reproduction cork extraction [19]. The percentages of each raw cork material were calculated from the average production of the 5 cork oak forest exploitations studied. Other distributions could be found according to different forest situations: the age of the trees, whether a fire occurred some time ago, if the owner decided not to carry out extraction for various reasons, and so on. In fact, because of their nature, forests are complex systems, but despite this, similar management is required to obtain the FU of a tonne of cork, and the same results could then be obtained regardless of the type of raw cork material extracted. In our study, the cork oak forests are mature and they consist of a mixture of trees of different ages; this situation is very common in Catalonia in order to guarantee the natural regeneration of cork oak forests. At the end of this paper, a sensitivity analysis of environmental impact distribution among both co-products will be carried out.

### 3.3.3. Description of the system

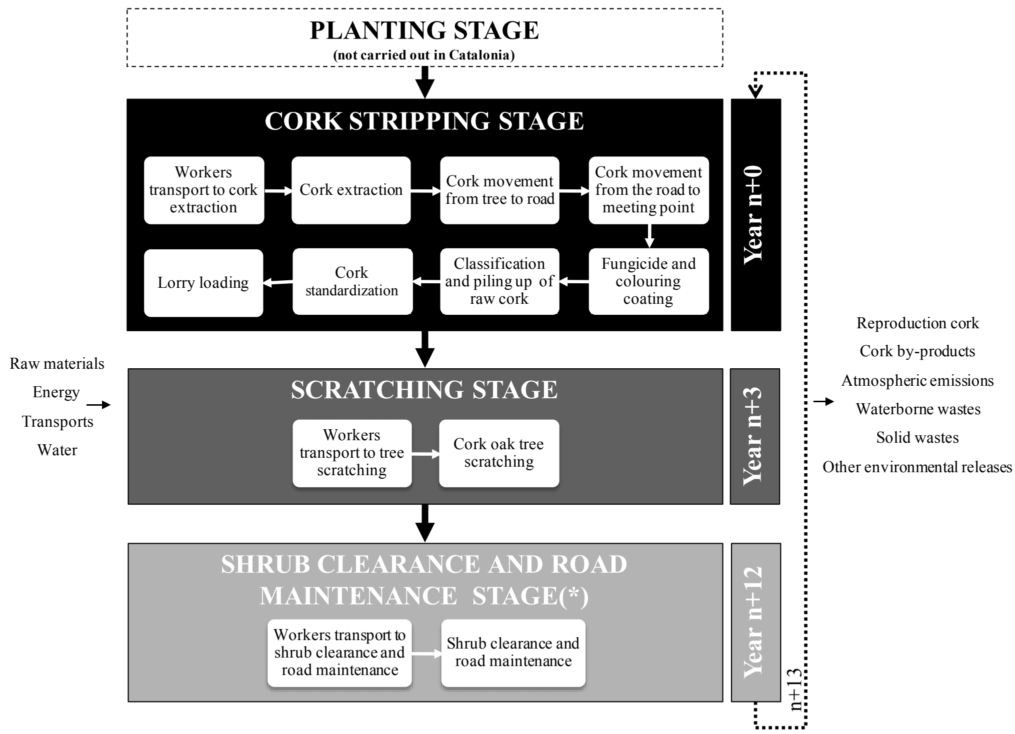
The analysis of cork oak forest exploitation from a life cycle assessment perspective is complex because the products extracted nowadays are the result of past forestry management activities, and activities carried out in our time will generate future raw cork material. Applying LCA methodology in long-term systems could be difficult because obtaining data from the activities performed during the last 200 years seems to be practically impossible: the technology used nowadays is not the same as 200 years ago, and future extraction could also be different if the traditional sector starts to technologize. Reporting information about the complete cycle could mean devoting a lot of time and work to collecting and processing. Nevertheless, the cork oak tree cycle can be divided into similar periods of 13 years. During each period, the same activities are repeated. Thanks to this approach, the current paper can avoid collecting data from the past 200 years.

In general, cork oak forests are a cyclical system formed by four cyclical stages: (a) the planting stage, (b) cork stripping, (c) scratching, and (d) shrub clearance and road maintenance. Under normal conditions, the planting stage does not take place in Catalonia because of the natural regeneration and growth of the trees. Planting only takes place in very few cases where severe wildfires have occurred. This stage is more typical of a silviculture exploitation model: more mechanized and organised. Figure 3.2 presents the main stages and their respective operations.

Due to the periodic removal of cork every 13 years in Catalonia, landowners tend to divide their properties into 13 similar plots, with one part exploited every year in order to guarantee the production of raw cork material and to spread financial revenues over time. Thus, each year, one part of the forest exploitation is stripped,

[4] Cork by-products are a group of raw cork materials consisting of virgin cork, which is the first cork obtained from the tree, and which shows deep fractures, second cork, the cork extracted after virgin cork extraction, which also has deep fractures, fragments of reproduction cork for the natural cork industry, cork slabs with defects, and others. They are mainly used to make granulated-agglomerated products.

another is scratched and another undergoes forest maintenance. The plot that will be scratched is the one exploited three years ago, and the one undergoing forest maintenance is the one that will be stripped the following year. This means all the cork extracted requires these three processes and their respective operations (Figure 3.2).




(1) Some years ago, owners carried out an additional shrub clearance and road maintenance operation every 6 years, but this operation has practically disappeared due to high costs.

**Figure 3.2. System framework for the raw cork material life cycle in cork oak forests.**

## *Cork stripping*

This stage consists of the extraction of the raw material every 13 years. It is always carried out at the beginning of summer, between June and July, by a team of workers who can extract 500 kg of raw cork per day. This stage consists of different operations. First, workers are transported by all-terrain vehicle to the area that is to be exploited. A manual stripping operation then takes place and the raw cork material obtained is moved to the road. Stripping is a very precise operation performed manually by expert workers using axes. The stripper makes long cuts in the cork, both vertically and horizontally, allowing large pieces of cork – the cork slabs – to be detached (figure 3.3).

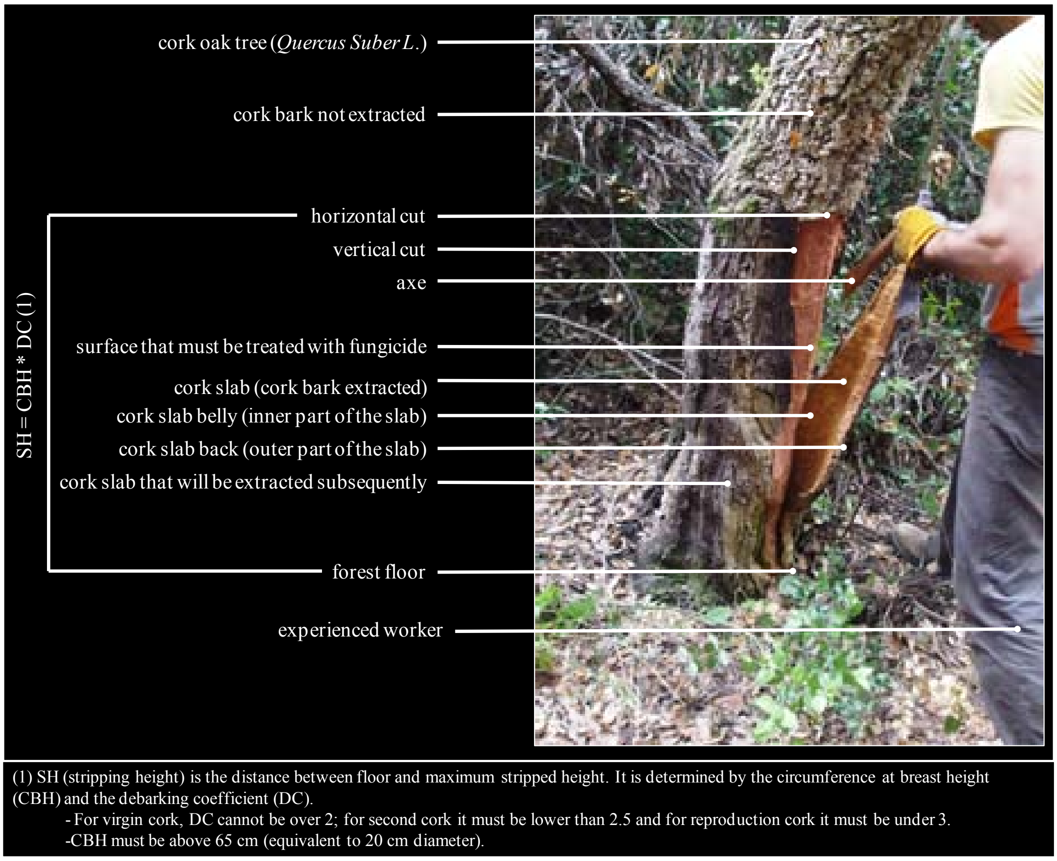



**Figure 3.3. Cork extraction: basic elements and determination of stripping height.** ***Source: Jesús Rives.***

The cork cambium is destroyed during the cork stripping process, but sustainable production is ensured because this species has the ability to regenerate a new cambium in the inner part of the bark, immediately below the cells that die as a consequence of cork stripping [49]. The stripping height is determined by a specific debarking coefficient [56] described in Figure 3.3, but, in fact, it is often determined by the stripping worker, who has sufficient experience to do this.

After stripping, another worker collects the cork slabs and little pieces of cork manually, and loads them on to an all-terrain vehicle. When it is completely full, the raw material is transported to a meeting point in the forest. Alongside these operations, another worker sprays a fungicide with a colorant to prevent *Diplodia mutila,* which causes withering and cankers on trunks and branches [166]. Meanwhile, cork slabs are accumulated at the meeting point, classified and piled up. Sometimes, cork slabs are homogenised before being loaded on to a lorry to transport the material to the industrial plants. Most of the operations are performed manually.

### *Scratching stage*

The scratching stage is carried out 3 years after cork stripping and it is done to facilitate future cork extraction. This practice is usual in Catalonia but not in other areas. This stage consists of two operations: the transport of workers in an all-terrain vehicle, and the specific scratching operation that consists of one or more vertical incisions to facilitate the growth of the cork bark, preventing fractures in order to get quality cork in the future [25]. Nowadays, some owners have decided not to carry out the scratching operation to reduce costs, but the practice is still quite common.

### *Shrub clearance and road maintenance*

This is the last stage that is performed to facilitate cork extraction. This stage also consists of two specific operations: the transport of the workers and the shrub clearance and road maintenance. This traditional practice is aimed at facilitating cork extraction, increasing cork yield by reducing competition from neighbouring shrubs and trees and reducing fire risk by reducing the fuel load [161]. Shrub clearance and road maintenance operations include different activities that could not be assessed separately because their division is unclear and arbitrary and there is currently no data available for each operation: selective cutting of trees to reduce density per hectare and prevent intraspecies and interspecies competition, removal of very old, decrepit trees or those that do not produce cork of sufficient quality, reducing fire risk, opening new roads providing access to the forest, and so on. Determining whether the function is carried out because of one or other activity is arbitrary and it was found more appropriate to make all these activities into an aggregate operation.

## 3.3.4. Boundaries of the system and other considerations

Cork oak forests generate different products and environmental services: honey, firewood, pine cones and pine nuts, green tourism, and so on, but cork is the only product considered in this study because practically all the management carried out is because of this natural, renewable and local resource. Only stages and operations related to cork extraction were considered in the system described in Figure 3.2, while operations related specifically to other products were excluded because the quantities of these goods are smaller than for cork, they are heterogeneous products and they represent lower financial income. The shrub clearance and road maintenance stage is necessary for all the other goods obtained from the forest, and distributing the environmental burdens of this stage between all these products after system expansion would be the best approach, but then the system would become more complex and specific allocation rules would have to be introduced. It was decided to attribute all the impacts of these stages to cork because this is the resource that articulates these forests, as it represents the highest revenues from the ecosystem.

As the raw cork material obtained nowadays is the result of the last few decades, it was assumed that similar technology is used to generate current and future cork. This is not actually the case for thiophanate-methyl fungicide because some years ago benomyl fungicide was used, before it was discouraged and banned [167]. Due to lack of knowledge of the composition of the colouring, this flow was quantified at the inventory phase but not considered in the life cycle impact assessment. It must also be taken into account that LCA methodology excludes the impact of manual human operations, and most operations in the system are entirely manual.

### 3.3.5. Life cycle inventory (LCI)

After fieldwork at one of the cork oak exploitations, a general system was defined for carrying out the environmental evaluation using LCA methodology. Then a specific questionnaire, known as the cork oak forest management questionnaire, was developed in order to collect inventory data. The system covered the whole raw cork material extraction cycle, and all the inputs and outputs associated with the achievement of these FU were considered. The cork oak forest management questionnaire consisted of five parts: general information, cork stripping stage, scratching stage, shrub clearance and road maintenance stage, and the collection of other forestry products (table 3.2).

**Table 3.2. Information headings requested in the cork oak forest management questionnaire used during the data collection phase.**

| Forest management questionnaire headings | Type of information demanded |
|---|---|
| General information on the exploitation | - Altitude above sea level<br>- Average annual temperature<br>- Number of workers<br>- Forest cover<br>- Number of cork oak trees by age<br>- Number of other tree species<br>- Percentage and types of shrub<br>- Cork production in recent years<br>- Production of other non-cork forestry products |
| Cork stripping stage | - Transport of workers to stripping<br>- Stripping operation<br>- Transport of the cork from the tree to the road<br>- Transport of the cork from the road to the central meeting point<br>- Fungicide spraying<br>- Classification and piling up of cork<br>- Lorry loading |
| Scratching stage | - Transport of workers to scratching<br>- Scratching operation |
| Shrub clearance and road maintenance stage | - Transport of workers to shrub clearance and road maintenance<br>- Shrub clearance and road maintenance<br>- Other specific maintenance operations |
| Collection of other forestry products | - Transport of workers to exploitation of other forestry products<br>- Operations related to exploitation of other forestry products |

In the end, the last part of the questionnaire (collection of other forestry products), was not used, because these resources and their respective operations were excluded from the system to avoid allocation procedures and because they were negligible compared with cork raw material management in quantitative and financial terms.

After a cork oak forest questionnaire model was drawn up, it was sent to the five forest exploitations in order to obtain all the requested information. During data collection, two specific workshops with stakeholders were carried out in order to explain how to fill in the information required and to answer queries. Afterwards, the questionnaires were checked and confirmed, firstly by the Catalan Forestry Consortium and secondly by the Catalan Cork Institute.

After the completed individual questionnaires were obtained, they were standardised and adapted to the FU. Then, the five inventories were averaged because the aim of the research was to quantify the environmental impact of cork oak forests in Catalonia as a sector, and not as individual forest exploitations.

### 3.3.6. Quality data and software

The software tool Gabi 4.4 [145] was used for modelling the system from a life cycle perspective. The environmental impacts were evaluated by using the CML 2001 method [138]. Local data obtained from the forest management questionnaires and averaged from the five exploitations was used to perform this research. However, the Ecoinvent v2.2 database was used to complete the life cycle inventory for general processes [141-143].

This study considered only the classification and characterisation phases of the LCA methodology, while normalisation, grouping and weighting of the results were not carried out. The impact categories considered were: Abiotic Depletion Potential (ADP), Global Warming Potential (GWP 100 years), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Layer Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), Human Toxicity Potential (HTP), Terrestric Ecotoxicity Potential (TETP), Freshwater Aquatic Ecotoxicity Potential (FAETP) and Marine Aquatic Ecotoxicity Potential (MAETP), Radioactive Potential (RAD). Other environmental aspects of cork oak forests, such as water use, land use or biodiversity, should be included in future under an LCA approach but, at the moment, the methodology is under research and development [168].

## 3.4. Results and discussion

The following section presents the environmental burdens associated with the extraction of a tonne of raw cork (FU). The stages and operations in the life cycle of raw cork extraction that pollute most will also be determined. In addition, an overall carbon dioxide balance of the material will be performed. Finally, a sensitivity analysis will be carried out.

### 3.4.1. Inventory data associated with a tonne of raw cork material (FU) in Catalonia

Table 3.3 summarises the main characteristics of the five cork oak exploitations selected for this study. It can be observed that the average number of workers is 6, rising to 8 during the cork extraction period. At the same time, it should be noted that there were different sizes of exploitations, small and medium-sized, ranging from 273-750 ha. One important feature is the total cork produced in an exploitation, which varies very considerably depending on the exploitation and the year. A range of 10-96 t of cork extracted per year was found. This large difference could be for several reasons but is mainly because of the nature and heterogeneity of the system, and the owner's decisions. There could be several natural reasons: it may be that the plot to be exploited that specific year is smaller or larger than average, or is less or more productive than average due to environmental conditions or the trees are older or younger, etc. The owner's decisions include delaying or advancing the progress of cork extraction depending on the cork market price or public subsidies.

**Table 3.3. Data characterizing the five cork oak exploitations in the experiment.**

| | Cork oak exploitations in the experiment | | | | | Sector average |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| Number of workers | 4 | 4 | 9 | 4 | 9 | 6 |
| Number of workers during cork extraction | 8 | 4 | 10 | 8 | 9 | 8 |
| Total cork oak surface (ha) | 260 | 375 | 750 | 310 | 273 | 394 |
| Annual area exploited (ha/year) | 19 | 29 | 58 | 24 | 21 | 30 |
| Road density in forest (m/ha) | 35 | 50 | 150 | 229 | 140 | 121 |
| Total cork produced in 2008 (t) | 31 | 49 | 96 | 11 | 56 | 49 |
| Total cork produced in 2007 (t) | 48 | 56 | 78 | 10 | 49 | 48 |
| Total cork produced in 2006 (t) | 42 | 50 | 66 | 13 | 36 | 41 |
| Total cork produced in 2005 (t) | 45 | 56 | 75 | 11 | 50 | 47 |
| Average cork extracted (kg/ha/year) (1) | 160 | 141 | 105 | 36 | 175 | 123 |

(1) Average cork extracted by year and area was for the period 2005-2008 and extrapolated to the 13-year cycle

The average cork extracted by year and area in the sector gives a result of 123 kg of cork/ha/year. However, from the analysis of the exploitations it can be seen that this value ranges from 36 to 175 kg/ha/year. These differences are clearly attributable to the age of the trees in each case: exploitation D only has trees younger than 50 years old that are just starting to be exploited and are still are not producing reproduction cork, while E is a more mature forest with 37% of trees over 100 years old, which have been stripped more than 6 times. A sector annual average production per hectare of 150 kg/ha/year was used because, if we do not take exploitation D into account, the average is 145 kg/ha/year, a similar value to that given by [20] and also indicated by the Catalan Forestry Consortium [66]. A sensitivity analysis of cork yield production per year and hectare will be carried out at the end of the paper in order to analyse how this factor could affect the results.

As shown in table 3.3, the forest average road density is 121 m/ha, which is very similar to that recommended for cork oak forests of 120 m/ha [56]. These roads are 2-3 metres wide. However, this parameter ranges from 35 to 229 m/ha depending on the exploitation analysed. These differences are attributed to different management practices, decisions or investments by the owners.

To obtain quality data about the cork actually extracted every year it is fundamental to have historical records of areas exploited and cork produced every year. This represents a large investment in time and financial resources for data collection and fieldwork, and current forest systems do not have that level of systematic organization. Improved collection of basic data is essential to achieve optimised systems and to carry out future research.

In Catalonia, due to natural forest regeneration, fewer inputs may be required than in other areas because planting-related operations are not necessary. Table 3.4 shows the main average flows associated with the FU. As can be seen, the only materials associated with the life cycle of the raw material were thiophanate-methyl fungicide, the colouring for painting the treated trees, and water. All of these are mixed in a backpack sprayer and used in the fungicide operation carried out after the cork stripping. The most important flow associated with the FU was the transport of workers to perform the different management operations. All these distances were calculated taking averages of the five forest exploitations analysed, always considering round trips. An average distance of 50 km with an all-terrain vehicle was found for transporting the workers to the area for exploitation, the same distance for collecting the cork and transporting it to the meeting point. Transport flows corresponded to system averages but, in fact, they depended directly on different circumstances, such as the geography of each particular area or the actual distance of each extraction point. Local transport of 100 km was estimated from the producer of fungicide and colouring to the exploitations. Besides transportation, forestry tractor machinery was required to maintain and clean the roads for access to the trees and to prevent fires. The biomass generated, comprising shrubs, tree branches, leaves and other parts is nowadays left in the forests to prevent nutrient loss.

**Table 3.4. Inventory data for collecting a tonne of raw cork (FU) from the cork oak forests of Catalonia.**

| INPUTS | | |
|---|---|---|
| **Flows** | **Average quantities** | **Variability range (%) (1)** |
| ***Materials*** | | |
| Fungicide (Thiophanate-methyl 45%) (l) | 0.1 | 95 -112 |
| Colouring (tekron) (l) | 0.1 | 95 -112 |
| Water (l) | 119.8 | 95-112 |
| ***Transports*** | | |
| By all-terrain vehicle (workers to stripping) (km) (2) | 53.2 | 50 - 226 |
| By all-terrain vehicle (cork to meeting point) (km) (2) | 53.2 | 50 - 226 |
| By all-terrain vehicle (workers to scratching) (km) (2) | 16.6 | 0 - 120 |
| By all-terrain vehicle (workers to shrub clearance and road maintenance (km)) | 28.4 | 35 - 141 |
| By van (auxiliary materials) (3) | 100 | - |
| ***Machinery*** | | |
| Forestry tractor (km) | 0.8 | 29-191 |
| **OUTPUTS** | | |
| **Flows** | **Quantities average** | |
| ***Products*** | | |
| Raw cork (t) – FU (4) | 1 | |
| Reproduction cork (t) (4) | 0.86 | |
| Cork by-products (virgin cork, second cork and other corks) (t) (4) | 0.14 | |

(1) This variability represents the differences in inputs required to obtain the FU in percentage for the best and worst forest exploitation.

(2) Average calculated from individual inventories and considering round-trip transport.

(3) Estimated average considering that fungicide and colouring are produced in local industries [56].

(4) This was calculated from the average of the five cork exploitations analysed.

The variability range is an indicator of the differences in inputs required to produce the FU between different forest exploitations. The lowest percentage corresponded to the forest exploitation using fewest resources, shorter transport distances or generating less raw cork of this type. For example, in the case of water this indicator is 95-112, which means that the best producer required only 95% of the average material, 114 l, while the company using the most needed 134 l for the FU. The same percentages can be observed for fungicide and colouring because the composition of the mixture is determined by the authorities [169], but, as the application is manual, some forest exploitations used more of the mixture than others.

### 3.4.2. Impact assessment associated with the forestry extraction of a tonne of raw cork material in Catalonia.

Table 3.5 presents the total environmental impacts associated with the production of a tonne of raw cork (FU) in Catalonia. As different parameters could affect the results of an individual exploitation, it was found to be preferable to analyse the cork sector by averaging data from different exploitations and obtaining sector results in Catalonia, avoiding comparison between different forest exploitations.

**Table 3.5. Total environmental impact associated with one tonne of raw cork extracted from cork oak forest in Catalonia considering an average production yield of 150 kg of cork/ha/year.**

| Impact Category | Units | Cork stripping stage | Scratching stage | Shrub clearance and road maintenance stage | Total environmental impact |
|---|---|---|---|---|---|
| ADP | kg Sb eq. | 1.00 | 0.09 | 0.23 | 1.32 |
| GWP | kg $CO_2$ eq. | 145.16 | 12.85 | 33.78 | 191.79 |
| AP | kg $SO_2$ eq. | 0.64 | 0.06 | 0.17 | 0.87 |
| EP | kg $PO_4^{3-}$ eq. | 0.12 | 0.01 | 0.03 | 0.16 |
| ODP | kg CFC11 eq. | 2.02E-05 | 1.79E-06 | 4.46E-06 | 2.65E-05 |
| POCP | kg $C_2H_4$ eq. | 0.14 | 0.01 | 0.03 | 0.18 |
| HTP | kg 1.4 DB eq. | 36.55 | 3.22 | 10.56 | 50.33 |
| TETP | kg 1.4 DB eq. | 0.81 | 0.07 | 0.26 | 1.14 |
| FAETP | kg 1.4 DB eq. | 9.06 | 0.80 | 3.01 | 12.87 |
| MAETP | kg 1.4 DB eq. | 3.23E+04 | 2.83E+03 | 1.17E+04 | 4.68E+04 |
| RAD | Daly eq. | 2.07E-06 | 1.84E-07 | 8.82E-07 | 3.14E-06 |

The impact assessment of cork extraction in Catalonia by stages can be seen in figure 3.4. As can be observed, most of the environmental burdens of the system must be attributed to the stripping stage. This stage accounts for between 66% and 76% of all the impacts, depending on the environmental category analysed. The shrub clearance and road maintenance stage contributes between 17% and 28%, and the scratching stage represents 7-8% of the impacts.

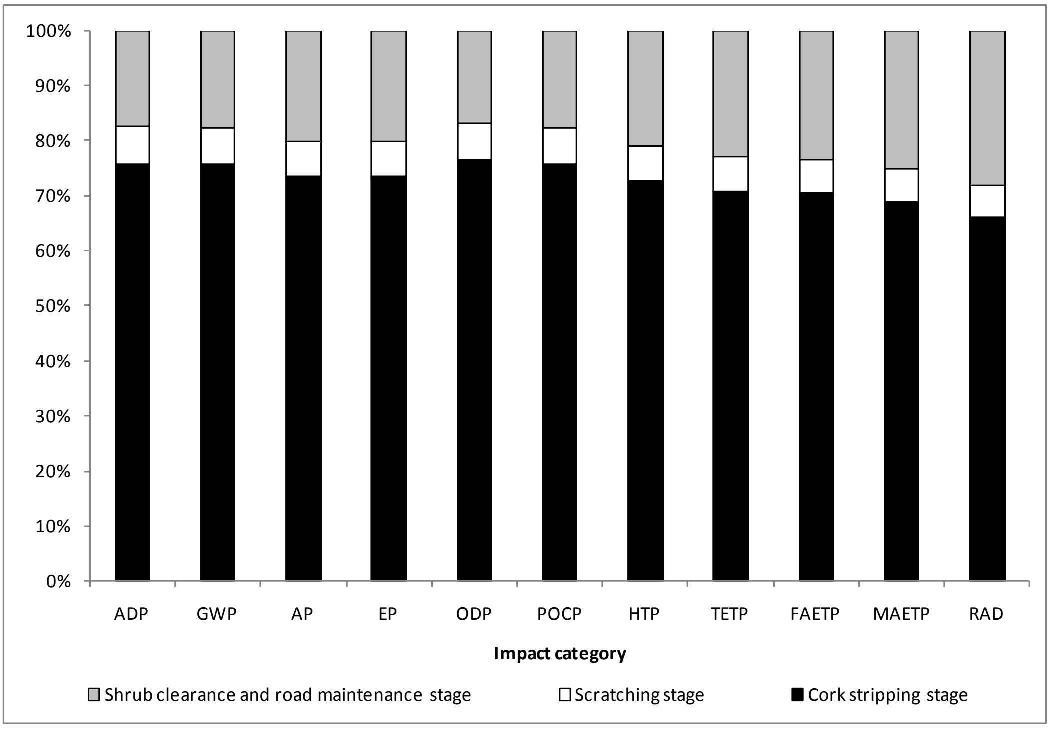
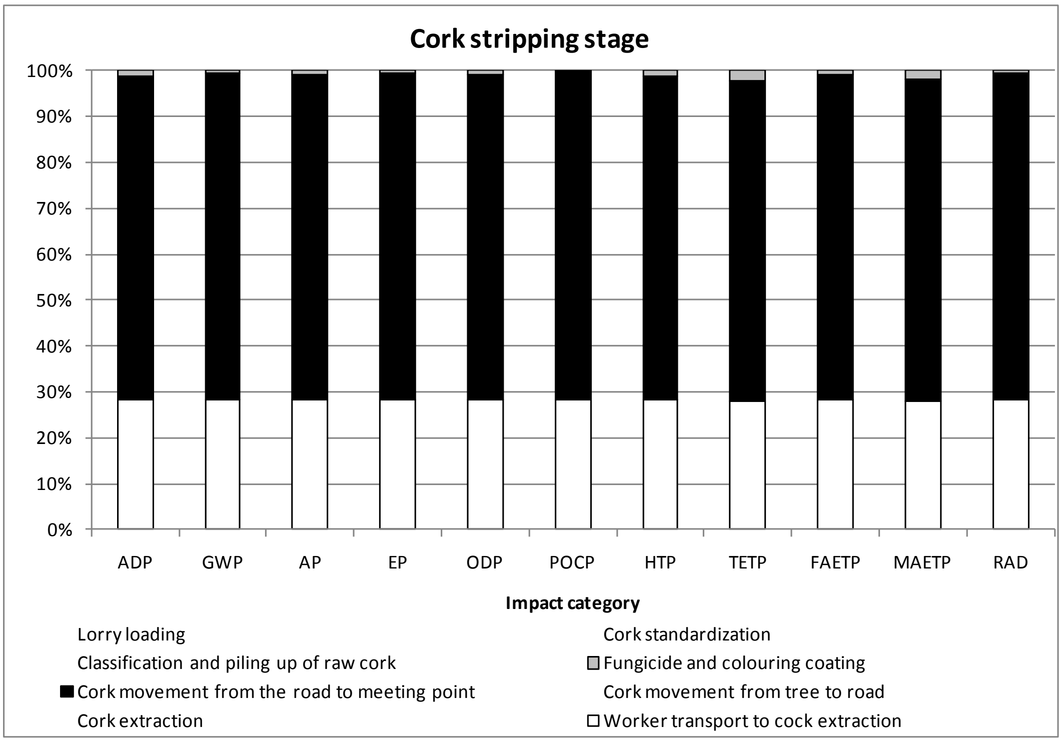



**Figure 3.4. Environmental impact assessment of raw cork material extraction by forestry stages in Catalonia.**

The three stages will now be disaggregated in order to detect which of their operations cause these environmental impacts. In figure 3.5, it can be observed that cork movement from the road to the meeting point was the operation that contributes most to the impacts caused during the cork stripping stage: between 70% and 71% for all the categories. Worker transport to the cork stripping site also made a significant contribution: 28% of that for all categories. By contrast, fungicide and colouring coating contribute at most 2%, and all the other operations: cork extraction, cork movement from the tree to the road, classification and piling up of raw cork, cork standardisation and lorry loading do not contribute to the environmental impacts of this stage because they are entirely manual activities, carried out as they have been done for many decades.

Figure 3.6 presents the shrub clearance and road maintenance stage disaggregated in both operations: the transport of the workers and the specific operation of shrub clearance and road maintenance, which, as explained in the system description, corresponded to different activities that cannot be separated. Both operations have a contribution of 35-70%, depending on the category considered.




* Lorry loading, classification and pilling up of raw cork, cork extraction, cork standardization and cork movement from the tree to road were manually operations.

**Figure 3.5. Environmental impact assessment of the cork stripping stage associated with raw cork material extraction in Catalonia.**

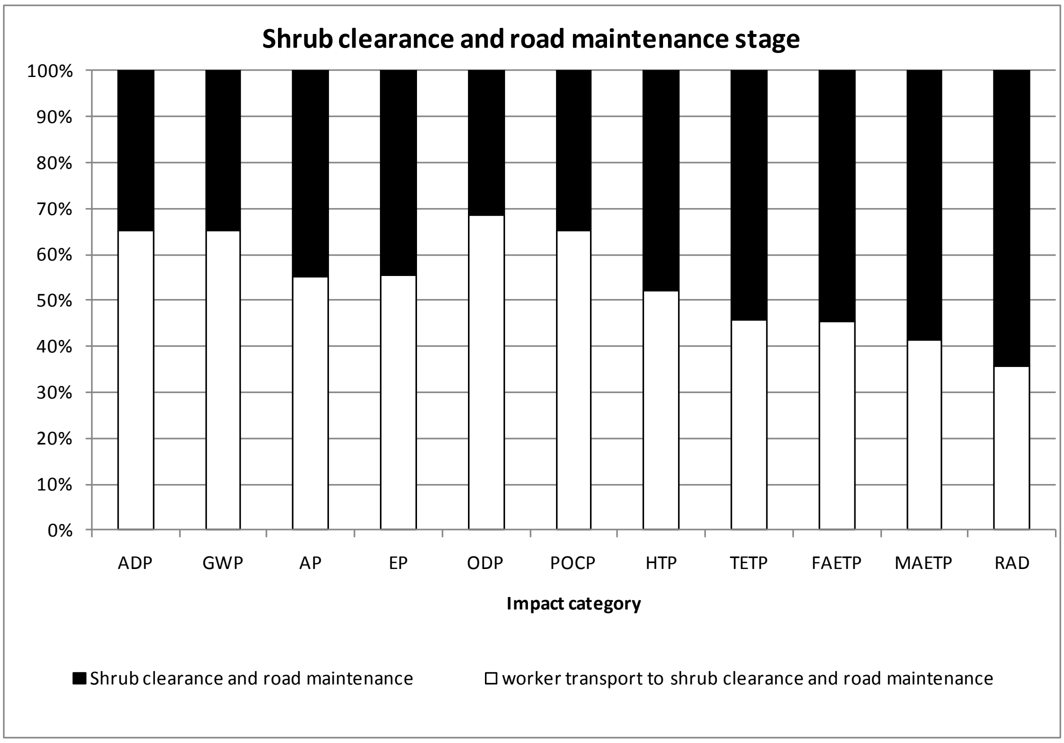



**Figure 3.6. Environmental impact assessment of the shrub clearance and road maintenance stage associated with raw cork material extraction in Catalonia.**

All the environmental impact associated with the scratching stage is a result of worker transport, because the specific scratching operation is performed manually, using axes.

According to the results for the stages and operations, improving transportation operations associated with workers and cork would be an important environmental measure, from a cleaner production point of view, to reduce the potential environmental impacts of the material. Also, an improvement of the shrub clearance and road maintenance operation would lead to a significant reduction in impacts, while the reduction of other operations would have very little effect on the overall results. In addition, increasing the productivity of the forests could improve the environmental performance of the raw cork material, but this seems to be very difficult due to climatic factors and the environmental limitations of the species.

An important fact that must be noted is the special value of some forest services, such as biodiversity conservation, soil erosion prevention, hydrology regulation, etc. which are difficult to evaluate according to economic criteria. These aspects must be considered in future LCA impact categories and in future studies.

### 3.4.3. Carbon dioxide balance associated with a tonne of raw cork material

On one hand, an average emission of 190 kg of $CO_2$ eq. per t of raw cork extracted (FU) was found in Catalonia forests, as stated in table 3.5. This is 29 kg of $CO_2$ eq./ha/year caused by cork extraction operations, according to the average production cork yield of 150 kg/ha/year. On the other hand, besides producing oxygen through photosynthesis, the unique cellular structure of cork contributes to $CO_2$ fixation. Cork oak forests play an important role in the global C budget. As with old-growth forests, cork oak forests accumulate and maintain C stocks for long periods.

Local data about $CO_2$ fixation in Catalonia in cork oak forests indicates that 0.78 t C [165] are fixed yearly per hectare: 2.9 t of $CO_2$/ha/year. *A priori*, it might, then, be thought that the carbon fixed by cork oak forests is clearly greater than the emission produced during their exploitation. It must be considered that not all the carbon fixed will be stored, because when cork is extracted some of this carbon is taken out of the system and contained in different products which, after their useful lives, will be disposed of and the carbon stored in the material returned to the atmosphere. However, the cork stripped from the tree represents at most 4% of the total biomass produced between successive cork extractions [14], and therefore has very little effect on ecosystem C storage. In cork oak forests, trees grow for more than 200 years and carbon is consequently accumulating, even though a small part of it is extracted and contained in the cork products. Accordingly, cork exploitation does not affect the ecosystem carbon sink role, as could happen in those forests exploited for wood where the trees are cut down and most of the carbon stored is transformed into a product before being returned to the atmosphere after its useful life.

Overall $CO_{2}$, balance = $CO_{2,\ \text{fixed by cork oak forests}} - CO_{2,\ \text{emitted during cork extraction}} - CO_{2\ \text{extracted in products (1)}}$

(1) The $CO_{2\ \text{extracted in products}}$ corresponds to the $CO_2$ contained in the cork extracted that will return to the atmosphere after useful life of the products that will be produced with the resource. It is assumed that the useful life of all products was less than 100 years.

$$CO_{2\ \text{extracted in products}} = 0.04 * CO_{2,\ \text{fixed}}$$

**Equation 3.1. Overall carbon dioxide balance considering the cork oak forest fixation, the emission generated during cork extraction, and the carbon contained in the cork products.**

Equation 1 describes how the carbon dioxide balance was made. The overall $CO_2$ balance result is that 2.75 t of $CO_2$ eq./ha/year is fixed by cork oak forests in Catalonia. This represents 18 t of $CO_2$ eq. per t of raw cork extracted (FU). In accordance with the fact that Catalonia has 63,000 ha of cork oak forests [68], more than 170,000 t of $CO_2$ are fixed annually by Catalan cork oak forests.

The Catalan fixation value per hectare used in this study was 2.9 t of $CO_2$/ha/year [165]. This value is lower than other (Portuguese) bibliographical references found: a cork oak forest with an average tree cover of 30% may fix 88 g $Cm^{-2}yr^{-1}$ during drought years, about 3.2 t of $CO_2$/ha/year [14]; or 140 g $Cm^{-2}$ $yr^{-1}$: 5.1 t of $CO_2$/ha/year [170]; or 4.8 million t of $CO_2$ per year are fixed in the 736,000 hectares corresponding to the Portuguese area: 6.5 t of $CO_2$/ha/year. If some of these Portuguese references were used to perform the balance, higher carbon dioxide fixation would be shown – even twice as much.

Carbon dioxide fixation should be researched deeply and verified by experimental methods measuring the growth of the forest and the cork oak trees. Reasons that could explain the differences between data from Catalonia and Portugal should also be discovered, as there is currently no explanation. *A priori*, if the density of forests is higher in Catalonia, the carbon dioxide fixation rate should also be higher. The differences could be due to different measurement methods or to different considerations and assumptions made.

In addition to the carbon balance and the production of a raw material, the management of cork oak forests is very important for the prevention of wildfires and for biodiversity conservation [171]. Cork also shows exceptional properties for producing many products: it is natural, local, renewable, impermeable to liquids and gases, compressible and flexible, and it has very low thermal conductivity and high energy-absorption capacity; with apparent lack of chemical reactivity, etc. [76]. Moreover, replacing non-renewable raw materials with cork in some applications could be an environmentally-friendly means of reducing the carbon footprint of products.

### 3.4.4. Sensitivity analysis

This section evaluates the influence of two parameters on the results. The first sensitivity analysis examines how lower or higher production yields in the forests could affect the results. The second deals with how environmental impacts could be distributed between the two co-products extracted from cork oak forests. In both subsections only four of the potential environmental impacts will be analysed, because the same trend will be observed for all the other categories.

#### *Effect of production yield on the environmental impacts associated with cork extraction*

This analysis will evaluate whether lower and higher production of raw cork material per hectare and year can influence the results. Table 3.6 presents the results for this sensitivity analysis. From the results, it can be observed that there is a direct proportion between production yield and the impacts caused: as cork production yields rise, lower environmental impacts are caused. This is obviously due to the fact that the FU will be collected in less space, shortening transport distances.

**Table 3.6. Sensitivity analysis of the effect on potential environmental impacts of lower and higher cork production per hectare and year.**

| Impact category | Units | Possible production yields of cork oak forests | | | |
|---|---|---|---|---|---|
| | | 50 kg/ha/year | 100 kg/ha/year | 150 kg/ha/year (reference) | 200 kg/ha/year |
| ADP | kg Sb eq. | 4.0 | 2.0 | 1.3 | 1.0 |
| GWP | kg $CO_2$ eq. | 575.4 | 287.7 | 191.8 | 143.8 |
| AP | kg $SO_2$ eq. | 2.6 | 1.3 | 0.9 | 0.6 |
| EP | kg $PO_4^{3-}$ eq. | 0.5 | 0.3 | 0.2 | 0.1 |
| $CO_2$ balance (1)(2) | kg $CO_2$ eq. | -55,104.6 | -27,552.3 | -18,368.3 | -13,776.1 |

(1) These carbon dioxide balances were carried out according to equation 1. Negative numbers indicate fixation of carbon dioxide, while a positive number indicates an emission.

(2) The carbon dioxide fixation of cork oak forests was set at 2.9 t of $CO_2$, although, if production is different, the fixation would also be different.

However, the relationship between cork yield production and the carbon dioxide balance is an inverse one, because if we set the carbon dioxide fixation of the cork oak forest at 2.9 t of $CO_2$, considering this as a constant even though different yields are obtained, more forest surface will be required to produce the FU and, consequently, carbon dioxide fixation will be higher. However, the carbon dioxide fixation rate should not be a constant, because it is influenced by different parameters, such as production yields (or the cork growth). Thus, with more yield production per hectare and year, there would be more forest growth and consequently more carbon dioxide would be fixed, causing the increase referenced in the bibliography.

The results are therefore clearly affected by the production yield and carbon fixation rate. In future, it is essential to study these aspects in depth, as was also found in section 4.3. However, this carbon dioxide balance is a first approach and should be improved when new data becomes available.

### *Distribution of environmental impacts between co-products: reproduction cork and cork by-products, depending on importance, mass and economic factors*

This section presents a sensitivity analysis of the distribution of environmental impacts in the system. The FU established only one output resulting from cork oak forests in Catalonia: raw cork material. In fact, the FU considered that 86% of the raw cork material was reproduction cork, and 14% corresponded to cork by-products. These percentages were calculated from the data supplied by forest exploitations, but they can vary notably depending on different factors, such as the age of the trees present in the forests or whether there has been a recent forest fire.

Economic considerations are important because reproduction cork had a value of 2070 €/t, while cork by-products had a value of 370 €/t [18], in 2009. Based on this, one can state that reproduction cork shows 5.6 times the value of other cork raw materials. According to these prices and the percentages of each component, an average tonne of raw cork (FU) in Catalonia had a price of 1840 €.

Four scenarios were analysed: the reference scenario (S1) considered only one output (a mix of reproduction cork and cork by-products), while the other scenarios tried to distribute the environmental burdens between the two outputs according to three factors: importance of the raw material, mass composition and economic price:

- Importance of the material. This distribution of impacts is based on the fact that reproduction cork is the real objective of the cork oak forest sector, while cork by-products are unavoidable. All the environmental impact is attributed to reproduction cork, while environmental burdens are not allocated to cork by-products (S2).
- Mass balance. This distribution is based on the percentages of each raw cork material obtained in the study. The environmental impacts are distributed between both outputs according to their quantities (S3).
- Economic price. Here, impacts were distributed according to the price of each output (S4).

In table 3.7, the sensitivity analyses associated with the proposed scenarios can be seen. Only some of the impact categories are presented but the same trend can be found for all of them.

**Table 3.7. Distribution of environmental impacts between co-products (reproduction cork and cork by-products) according to different factors: study reference data, importance of the material, mass balance, and economic price.**

| Impact Category | Units | Reference (S1) | Importance factor (S2) | | Mass factor (S3) | | Economical factor (S4) | |
|---|---|---|---|---|---|---|---|---|
| | | All cork (1) | Repro. cork (2) | Cork by-prod. (3) | Repro. cork | Repro. cork (2) | Cork by-prod. (3) | Repro. cork |
| ADP | kg Sb eq. | 1.3 | 1.3 | 0.0 | 1.1 | 0.2 | 1.1 | 0.2 |
| GWP | kg $CO_2$ eq. | 191.8 | 191.8 | 0.0 | 165.9 | 25.9 | 162.6 | 29.2 |
| AP | kg $SO_2$ eq. | 0.9 | 0.9 | 0.0 | 0.8 | 0.1 | 0.8 | 0.1 |
| EP | kg $PO_4^{3-}$ eq. | 0,2 | 0,2 | 0.0 | 0,2 | 0.0 | 0.2 | 0.0 |
| $CO_2$ balance (4) | kg $CO_2$ eq. | -18368,3 | -18368,3 | 0,0 | -15888,6 | -2479,7 | -15576,3 | -2792,0 |

(1) The environmental impacts consider both fractions.

(2) Reproduction cork is the fraction of raw cork material obtained in cork oak forests that has the highest economic value.

(3) Cork by-products are the fraction of raw cork material with the lowest economic value.

(4) Overall carbon dioxide balance. Negative results represent an overall fixation result.

S1 – Reference scenario. Results of this study.

S2 – In this scenario, we attribute 100% of the impacts generated to reproduction cork, while other cork raw materials have no environmental burdens because they are an unavoidable part of management.

S3 – In this scenario, allocation is distributed between both outputs according to the mass balance.

S4 – In this scenario, allocation is distributed between both outputs according to the economic balance.

S2 is an approach that gives importance only to reproduction cork, although it considers two outputs. It is not recommended because allocating 100% of the environmental burdens to these fractions would mean that the other fraction does not have economic value and this is not actually the case. S3 reflects the composition of both outputs very well, and distributes the impacts between them, but if the composition changes these burdens also change in proportion to it. The same can be seen in S4 but with the economic proportion. Considering only one output, as in S1, is adequate for presenting the results clearly, simplifying the system analysis, and avoiding environmental impact distribution. Moreover, the same results would have been obtained if other mass percentages or economic prices of both outputs had been found.

# 3.5. Conclusions

- The potential environmental impacts associated with raw cork extraction in cork oak forests can be observed in table 3.5. Analysis of the stages and operations involved in the forestry management system, revealed that between 66% - 76% of the impacts were caused by the stripping stage, while between 17% - 28% was caused by the shrub clearance and road maintenance stage. Movement of cork from the forest road to the central meeting point is the operation that contributes most to the impacts of the stripping stage: more than 70% for all the categories analysed. If the cork forestry sector wants to improve environmentally, this operation must be optimised.
- According to the results, 0.2 t of $CO_2$ eq. are emitted during the life cycle of a t of raw cork material, considering a production yield of 150 kg/ha/year.
- Although cork is extracted from the trees, they continue growing and fixing carbon dioxide, so the resulting carbon dioxide balance is that 18 t of $CO_2$ were fixed per t of raw cork extracted in Catalonia (Equation 1).
- Due to its unique properties and its low environmental impact, cork is a good alternative to non-renewable materials with a great impact on multiple products and applications. It could make a particularly useful contribution to reducing the carbon footprint of these products.
- Cork is a product of great ecological value, with many features that make it very interesting from a sustainability perspective because, in addition to its low emissions and the great potential for capturing $CO_2$, it generates economic revenues, provides jobs and development in rural areas, and allows many environmental services such as forest preservation, biodiversity conservation and wildfire prevention.
- LCA methodology was a good tool for the environmental assessment of raw cork extraction. The approach of dividing the system for a product with a lifespan of over 200 years into similar, shorter, repeated periods simplifies the analysis and avoids spending a great deal of time collecting data from the last two centuries.
- Sensitivity analysis proves that the results and the carbon dioxide balance of cork oak forests could be affected by the cork production yield, considering a range of between 50-200 kg/ha/year. Also, the sensitivity analysis of the distribution of impacts between reproduction cork and cork by-products demonstrates that considering only one output as FU simplifies the assessment and avoids distribution of impacts according to importance, mass balance or the economic price of the raw cork materials.
- Other impacts of forests, such as biodiversity conservation or soil erosion prevention, must also be evaluated from an environmental perspective in future research. In addition, economic quantification of direct and indirect services and resources obtained from these forests would be a complement to this LCA study. Also, in future research, the other cork oak agro-forestry model typical of Portugal and southern Spain must be analysed to obtain environmental data on both systems.

# PART III

## Environmental assessment of the cork industrial sector in Catalonia


# Chapter 4

# ENVIRONMENTAL ANALYSIS OF THE PRODUCTION OF NATURAL CORK STOPPERS IN SOUTHERN EUROPE (CATALONIA – SPAIN)

# 4. Environmental analysis of the production of natural cork stoppers in Southern Europe (Catalonia – Spain)

This chapter is based on the following paper:

- **Rives, J., Fernandez-Rodriguez, I., Rieradevall, J., Gabarrell, X. Environmental analysis of the production of natural cork stoppers in southern Europe (Catalonia - Spain). Journal of Cleaner Production, 2011. 19(2-3): p. 259-271.**

## Abstract

The wine industry has developed greatly over recent years, and it could be stated that what was once a traditional industry has become a very productive and technical sector. One aspect that has not been studied until now is the cork stopper, despite the fact that most wine bottles are sealed with this product, and practically all corks are produced in the Iberian Peninsula.

This study presents the environmental analysis of the production of natural cork stoppers, using life cycle assessment (LCA) methodology. The research was supported by data from four Catalan representative companies and all the stages involved in the production after the forest management have been taken into account. The purpose of this research was to provide reference data for the Catalan cork industrial sector (Northeast Spain), and also contribute to deciding which aspects of natural cork stopper production must be improved and further researched. Another objective of this research was to emphasise and demonstrate that LCA methodology could be an interesting tool for improving traditional industry, from a cleaner production perspective.

Results could be used by other sector companies to analyse and compare themselves with in order to know if they could improve their production with the current available technology. Impact assessment results indicate that the manufacturing stage was the stage causing the greatest impact, but also an evaluation of the influence of the initial transport from the forest reveals that this stage could notably increase the impact when raw cork was moved from distant forests.

## Keywords

Cork sector, eco-efficiency, ecomaterial, environmental impact, LCA, LCI, Mediterranean, stopper, wine.

# 4.1. Introduction

Cork oak (*Quercus suber L.)* sclerophyllous forests are located in the Mediterranean climate zone of Western Europe (Portugal, Spain, France and Italy) as well as in North Africa (Morocco, Algeria and Tunisia). The worldwide area occupied by cork oak is 2,277 thousand hectares and 55% of these are located in the Iberian Peninsula. The production of cork worldwide is about 300 thousand tonnes, more than 80% of which is produced in the Iberian Peninsula [18]. Apart from cork exploitation, cork forests are especially valuable because they are important reservoirs of biodiversity and they act as a carbon sink. It represents a model of sustainability between human activity and natural resources.

Many products from forest materials have been studied so far, such as wooden containers [156], energy [172], and paper [173], etc. But one of the smaller items stemming from forest resources that had not been studied in sufficient detail up until now are the natural cork stoppers, which are the most added value product made from cork.

The cork sector in the Mediterranean area is important due to the relevance of the wine sector in the EU, where 60% of the world’s wine production is concentrated (16.2 million tonnes of wine during 2008). Moreover, France and Italy were the first production countries comprising 17% of the production, while Spain was the third producer with 13% [174]. Some environmental strategies in the wine sector have been researched, such as the recovery of organic waste in the wine industry [175], or the economic and environmental analysis of wine bottle production in Spain by means of the life cycle assessment [176], while other aspects such as the environmental feasibility of natural cork stoppers have not been studied in such depth.

Cork is a natural, Mediterranean and renewable material which is very useful to produce different kind of products such as insulators, floorings, boards, insoles etc. The product that has become the most important economic resource for this ecomaterial is the cork stopper; natural stoppers for still wine and agglomerate stoppers for champagne and sparkling wine [22, 177]. The characteristics of cork, especially its impermeability to liquids and gases, its compressible and flexible nature, make it a suitable material to put at the top of wine bottles [76, 178]. Nevertheless, some authors argue that some problems could occur when a bottle is sealed with cork stoppers, especially cork taint due to 2,4,6-trichloroanisole (TCA) [86, 179-181]. Although some innovations and improvements have been introduced to guarantee quality, such as for example the use of electronic machines to select and classify the stoppers using cameras [182], the natural cork stopper industry has always been a traditional industry in which an important part of the processes are carried out manually, as for example the final visual checks that are performed by experienced people.

The area selected in which to carry out the research was Catalonia, located in the northeast of the Iberian Peninsula. In 2008, there were 82 companies involved in the cork industry in Catalonia, and the turnover reached 228.35 million Euros. Also, there were about 1,243 persons employed in the sector. This small product that was apparently of little relevance arrived to many houses worldwide because in Catalonia, 1,400 million natural cork stopper units were produced in 2008: this represented more than 10% of the global production [183].

The production of natural cork stoppers can be divided into different stages: the forest management, the preparation of slabs of reproduction cork [5], the manufacturing of the stoppers and the finishing. Due to this fragmentation, some transport takes place between the different stages (Figure 4.1). Forest management was excluded from this research because the aim of the study was to improve industrial processes from a cleaner production perspective, and not to improve the forestry practices. After extracting the cork and following subsequent stabilisation in the forest, it is transported to a Preparation factory, where the slabs are boiled and selected. Only those planks that are sufficiently thick are then transported to a natural cork stopper manufacturer, where they are then cut and punched into cylindrical pieces. Then, when the correct dimensions of the stoppers are obtained, they are sent to a finishing factory where the stoppers are cleaned and surface treated with paraffin or/and silicon to obtain the final product. Although some companies are involved in the whole process from start to finish, very often several companies participate in the process.

Sectorial studies, such as this case which has been working with four companies, are a means of covering a larger range of possibilities than when performing the study of one single company. From the environmental point of view we endeavour to set acceptable yet realistic impact thresholds. The inventory data were provided directly by different companies which presented a different, specific and representative profile of the industry in Catalonia (Northeast Spain). They were selected for various reasons:

- Their principal activity is to produce natural cork stoppers for still wine.
- All the companies have incorporated the ISO 9001 standards.
- They are members of AECORK (the Association of Cork Companies of Catalonia founded in 1977).
- They comprise medium and small enterprises with between 10 and 50 employees.
- The availability of recorded data.

The main objectives of the current research were to quantify the environmental impact of producing natural cork stoppers in Catalonia, and to determine which stages of the production cause most pollution. The results will be of interest to all companies in the cork sector, especially for producers of natural cork stoppers, to assess and compare their own impact, and to determine the feasibility of optimising their systems to increase their competitiveness. Moreover, as there is no official best available techniques (BAT) reference document for cork stopper manufacturing, this research could be a first approximation for the sector.

[5] Reproduction cork: obtained from the 3rd extraction onwards, because it is suitable for the production of stoppers for wine bottling.

## 4.2. Methodology

This gate-to-grave LCA study was used in order to quantify and compare the potential environmental impacts of producing natural cork stoppers. This study was based on the ISO 14040 regulations [109] that describe the four basic steps of the assessment procedure: (1) goal and scope definition, (2) Life cycle inventory (LCI), (3) Life cycle impact assessment (LCIA) and (4) Life cycle interpretation [118, 120, 137, 141].

In this case, the study was carried out from the transportation of the reproduction cork. Forest management was not included because the study focused on the industrial production.

### 4.2.1. Goal and scope definition

#### *Objective*

The main objective of this gate-to-grave LCA was to quantify and assess the environmental impact of natural cork stopper production by considering all the processes involved in their industrial production: from the initial transport of the reproduction cork from the forest to the obtaining of the final product; taking into consideration raw materials, energy, waste, emissions, etc. as well as all the flows involved. Results should identify the total emissions of natural cork stopper production and also, point out which processes contribute most to them.

#### *Functional Unit*

The function of the natural cork stopper is to protect the content of a bottle, saving its physical, chemical and quality characteristics. One million standard natural cork stoppers were considered to be the Functional Unit (FU), with all the flows referring to them.

Due to the variety present in natural cork stoppers depending on the dimensions, the quality of the raw cork and the required quality of the final product, a natural cork stopper model was established after reaching a consensus with experts and the Catalan Cork Institute. The main characteristics of the model were a diameter of 24±0.5 mm, a length of 44±49 mm and a weight of 3.7±0.3 g. This model was selected because this stopper represented the majority of the production.

#### *System description*

Companies producing natural cork stoppers are traditional industries which have their own way of producing, as was observed during the compilation of the data. This means that every company undertakes a specific production process, depending on the technology used and their own methods. It also means that different amounts of inputs and outputs were generated and that the same operation could be classified as one or another stage depending on the company. Consequently, a general framework for the life cycle of a natural cork stopper was considered taking into account these facts (Figure 4.1). In addition, some companies carry out all the production processes, while others only concentrate on one stage. These facts introduce complexity to the system and the calculations, which will be explained later. The particular system of each company could not be revealed due to professional secrecy and the confidentiality of the study.

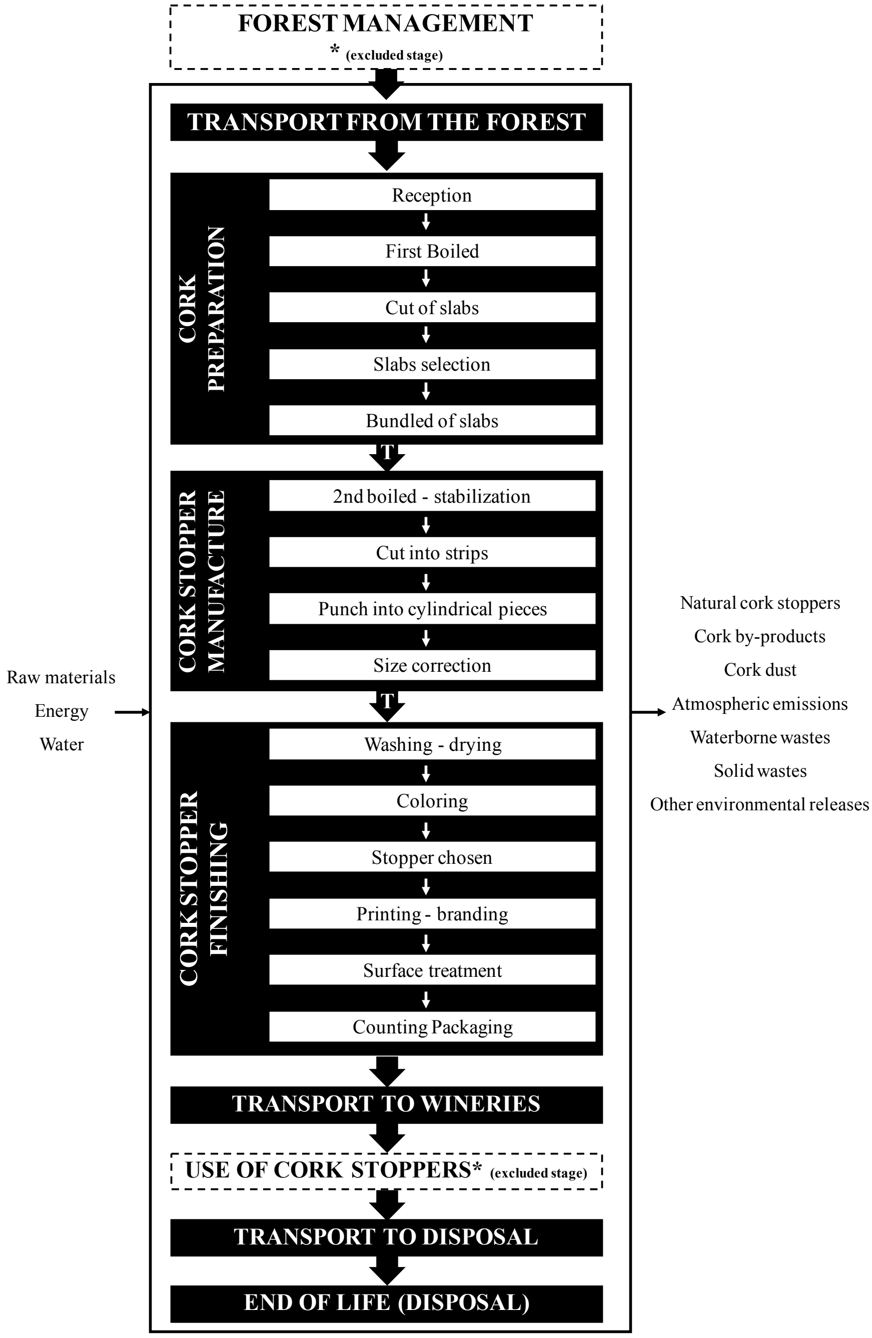



**Figure 4.1. General system framework of the life cycle of the industrial production of natural cork stoppers: stages and production processes considered.**

The current system, considered in this study, starts just after the reproduction cork has been extracted, and when it is transported to the factory. Later, the cork preparation stage starts. Consequently, different kinds of extracted cork are selected and eliminated because of unpleasant defects such as green cork, yellow spots or clayed cork. Furthermore, the main characteristic activity of this stage is to boil and stabilise the cork slabs. This is generally done by immersing the slabs in hot water (100ºC) in order to eliminate organic solids and to obtain humidity which is useful to process the slabs. Afterwards, a manual selection activity takes place, in order to select the widest and most useful slabs to manufacture natural cork stoppers, and that cork that cannot be used is sent to the cork agglomerate industry. Finally, and only if the producer of cork stoppers is located in a different factory plant, the selected slabs are bundled and transported to the subsequent manufacturing company. In many cases, the cork preparation is carried out by a specific company often considered as an auxiliary industry. Also, these companies are often located near the forest from where the raw cork was extracted, and it can be understood as a way of optimising the system, because they act as a filter, avoiding the transportation of useless raw cork.

The following stage is the manufacturing of the cork. This stage is composed of different processes such as boiling for a second time, cutting the cork into strips and punching it into cylindrical pieces, sanding the cork down in order to obtain the required length and diameter, and, in some cases, depending on the enterprise, selecting the cork using a machine with cameras, and manual selection carried out by experienced workers.

Before distribution, the cork stoppers are put through the finishing stage. It consists of different processes in order to optimise the quality of the products. Firstly, the stoppers are washed in order to eliminate microorganisms. Following this, the stoppers are selected. Later, a thin film of paraffin and/or silicone is applied to the cork stoppers to facilitate their insertion into and removal from the bottles. Subsequently, the stoppers are branded or printed with inks and/or fire. After packaging them, the corks are transported to bottlers and wineries.

After the cork stopper has been used by customers, a landfill is considered at the end of its life because recycling has not been introduced. The recovery of used cork stoppers would contribute to reduce waste and to a more sustainable development [70]. However, nowadays there are very few experiences of recovering corks. Furthermore, and because of the insufficient information available about the disposal of cork in landfills, it has been estimated that cork's behaviour would be similar to that of wood in terms of biogas production and its impact.

### *Boundaries of the system*

According to ISO 14040, certain categories of operations might be excluded from the systems. The consumption of resources and energy associated to bottling activities was considered out of the system, because the aim of this study was to quantify the environmental impact of the natural cork stoppers.

Because of the long useful life of industrial buildings and machines, and the high quantity of production, these elements were not taken into account as they were insignificant to the operation. Also, administrative, laboratory and business operations were excluded from the production impact.

Some inputs that represent a low percentage of the system (<2%) such as colourings, inks and detergents were quantified but not taken into account in the environmental analysis system. Their contribution to the main system could be negligible because they were used in very little quantities and they were transported from local industries. Moreover, there was a lack of information available in LCA databases and the composition of the product was unknown because the distributor company did not provide the information citing secrecy reasons.

The transport of auxiliary materials such as paraffin, silicone, hydrogen sulphur, etc., was not considered because it was negligible compared to the transport of reproduction cork; and because distributors of these materials were located near the Catalan (Northeast Spain) industries (<100km). Also, transportation of the cork by-products was excluded because some of them were used in the same factory or sent to a nearby company that agglomerated them. Moreover, their impact must be allocated to those products and not to natural cork stoppers. Also, the usage stage of the cork stoppers was not taken into account due to their low environmental impact compared with other stages involved in the LCA.

The wastewater was excluded from the LCA due to the lack of data available about their composition and their emissions. It was observed that companies are not obliged to measure the quality of the water after the boiling, and only in some cases do they measure some basic parameters such as pH, chemical oxygen demand (COD), total nitrogen or suspended materials.

### *Life cycle inventory (LCI)*

A general framework of the stages and operations involved in producing natural cork stoppers was established on the basis of consultations with the different cork industries, following the International Code of Cork Stopper Manufacturing Practice [184], and visiting companies and collecting data from them. Then a complete and complex questionnaire was prepared.

The questionnaire included a specific table for each individual operation, meaning a lot of tables were required. An example of one of these tables for one single operation can be observed in table 4.1. The questionnaire covered and collected data from the entire natural cork stopper production in five companies. Unfortunately, one company was not included in the results because the data reported were not of sufficient quality. It was reported data about all the stages: transport of the reproduction cork from the forest, the preparation, manufacture, and finishing, transport to wineries and transport and waste management. Besides, all these data were reported on a lower scale: the operation process. Data about different operations such as boiling, selection, size correction, etc., but also, secondary operations such as moving the natural cork stoppers into the factory using conveyor belts or using pneumatic systems were included and considered.

**Table 4.1. Example of a questionnaire-table useful to collect data about (a) the specific process of transport by vehicle from the forest stage and (b) the surface treatment operation in the finishing stage.**

| A1 - Vehicle route (lorries, vans, cars, etc.)* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ROUTE | | | | | | VEHICLE CHARACTERISTICS | | | | | LOAD | | OTHER | |
| *Origin company* | *Origin municipality* | *Receiving company* | *Receiving municipality* | *Route (main cities)* | *Total Km* | *Vehicle weight (t)* | *Vehicle capacity (m³)* | *Useful life (years)* | *Fuel consumption* | | *Cork quantity* | | *Other inputs* | |
| | | | | | | | | | *Value* | *Units* | *Value* | *Units* | *Value* | *Units* |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| **COMMENTS AND CONSIDERATIONS** | | | | | | | | | | | | | | |

* It is necessary fulfil at least a line for every farm that supplied cork.
** If different transports took place for the same farm or with different conditions (different vehicle, different vehicle capacity, different useful life, and so on) a different line must be fill out for each conditions.
*** Also, it must be indicated if the vehicle returns to the origin full of other products or empty.

| F15 – Surface treatment | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Machine type (1)* | *Machine weight (t)* | *Useful life (years)* | *Machine power (kW)* | *Year of purchase* | *Operation time (2)* | | *Cork quantity* | | *Energy resources (3)* | | *Water consumption* | | *Products consumption* | |
| | | | | | *Value* | *Units* | *Value* | *Value* | *Units* | *Value* | *Units* | *Units* | *Value* | *Units* |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| **COMMENTS AND CONSIDERATIONS** | | | | | | | | | | | | | | |

(1) It is necessary fulfil at least a line for every operation considered. If a manual operation takes place indicate it as "manual"
(2) Indicate the amount of time necessary to produce a determinate cork quantity.
(3) Indicate all the energy, water and materials in relation to each operation. Add a line for every product/material used.

In addition, general data of the factory were requested, such as the production of stoppers and by-products, water consumption, waste generated, intermediate transport, energy and resources not involved in a specific process, characteristics of all the machinery, etc., in order to quantify global environmental impacts not directly associated with an operation.

### *Quality data*

Some data were obtained from the machinery manuals and other data were obtained from the records of the assessed companies. All the producers reported the same kind of data because different meetings took place between enterprises, the Catalan Cork Institute and the authors, in which how to complete the questionnaire was agreed and explained.

After testing and verifying the questionnaire, it was sent to the companies in order to obtain all the raw data of the systems. After some months the companies collected and directly provided the data and once the questionnaires were answered, they were sent to the Catalan Cork Institute, a reference centre for cork research, where all the data was revised, controlled and checked. Moreover, all of the companies were visited and examined with the head of production of the companies or technical workers in order to verify the collected data.

### *Calculations and averages of the sector*

Because the main drive behind the research was to evaluate the cork sector, calculations and averages of the data collected had to be made. Also, due to secrecy reasons, data and specific explanations of the production system of one particular company could not be shown. Then, the complete life cycle of the production of natural cork stoppers was outlined, taking data from the four different enterprises.

Firstly, crude data from the companies were adapted to the FU. Due to the fact that the FU consider one million natural cork stoppers, as a final product, the calculations were performed in a backwards fashion, going from the end of the production process back to the transportation of the raw materials. Then, a table for each company was created in which the flows were quantified for each process. In order to obtain results for the sector, an average was taken from the calculated data of all the companies. If a company only contributed to the finishing or to the manufacturing stage, the other stages were not considered in the average, but they were calculated using the averages of the other companies in order to obtain comparable results.

Furthermore, a system in which all the production processes took place in the same plant without considering intermediate transports was assessed, due to its lower importance in the whole life cycle, because the complexity of the studied model would increase and because the objective of the study was to obtain a sector average, and not individual conditions.

## *Software*

The software Gabi 4.2 [185] and the CML 2001 method [138] were used in this study, in order to evaluate environmental impacts. All the impacts were allocated to the production of cork stoppers.

Data associated to producing natural cork stoppers were obtained directly from the completed inventory questionnaires carried out in the companies (local data), while general production processes associated to producing raw materials, energies, transport and waste management were obtained from Ecoinvent 1.2 database [141] (Table 4.2).

**Table 4.2. Summary of the data used from Ecoinvent 1.2 for the environmental analysis of natural cork stopper production.**

| Component | Source: Ecoinvent database |
|---|---|
| ***Materials*** | |
| Raw Cork | RER: raw cork, at forest road |
| Water | RER: tap water, at user |
| Hydrogen peroxide | RER: hydrogen peroxide, 50% in H2O, at plant |
| Paraffin | RER: paraffin, at plant |
| Silicone | RER: silicone product, at plant |
| Sulphur dioxide | RER: sulphur dioxide, liquid, at plant |
| Polyethylene (HDPE) | RER: polyethylene, HDPE, granulate, at plant |
| Aluminium | RER: aluminium, primary, at plant |
| Corrugated board | RER: corrugated board, recycling fibre, double wall, at plant |
| ***Energies*** | |
| Electricity | ES: electricity, medium voltage, at grid |
| Diesel | RER: diesel, at regional storage |
| Butane | RER: propane/ butane, at refinery |
| ***Transports*** | |
| Transport lorry | RER: transport, lorry 16t |
| Transport ship | OCE: transport, transoceanic freight ship |
| Transport wastes | CH: transport, municipal waste collection, lorry 21t |
| ***Waste Management*** | |
| Disposal of residues | CH: disposal, concrete, 5% water, to inert material landfill |

The LCA only considered the classification and characterisation phases, while normalisation, grouping and weighing of the results were carried out. The impact categories considered were: Abiotic Depletion Potential (ADP), Global Warming Potential (GWP 100 years), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Layer Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), Human Toxicity Potential (HTP), Terrestric Ecotoxicity Potential (TETP), Freshwater Aquatic Ecotoxicity Potential (FAETP) and Marine Aquatic Ecotoxicity Potential (MAETP).

# 4.3. Results and discussion

This section presents the LCA results for the production of natural cork stoppers. Additionally, an analysis to observe the influence of certain parameters on the results was carried out, according to the 14040 and 14044 ISO standards.

## 4.3.1. Inventory data of natural cork stopper production in Southern Europe (Catalonia – Spain)

Inventory data were obtained from the industry questionnaires. The main average flows to produce and distribute one million natural cork stoppers (FU) are reported in Table 4.3. One of the main facts that can be observed in the table is that at the beginning of the life cycle, 13.8 t of reproduction cork were required to produce the FU. This 13.8 t only represents 30% of the raw cork extracted from the forest, because the rest was not suitable to produce cork stoppers and it was used directly in agglomerate industries. Considering that the FU initially weighed 3.7 t, it is evident that 3.7 times the mass of cork was required to produce a unit. This could be considered as a great loss of raw material during the production cycle.

It can also be observed in table 4.3 that some input flows varied significantly depending on the company. For example, the use of reproduction cork to produce the FU varies from 74% to 150%. This means that some companies needed fewer raw materials because their whole production process is more optimised than that of other companies. This fact also could be observed in the majority of flows, but in some of them the variability is greater than in others. The greatest difference observed was for the aluminium used in the packaging (0 to 400%), and for butane, due to the fact that there are companies which did not use bags of aluminium to protect their product or used another resource of energy other than butane. Those companies using more inputs may also have greater economical costs, and it may also imply a lower competitiveness.

The results considered three transportations. The first is that corresponding to the displacement of the raw cork from the forest to the factory; in this case the average distance was about 741.3 km (Southern Europe). The range of variability was high (3 – 169%) because while some companies used local reproduction cork, others used cork from other productive areas such as Portugal or Southern Spain (mainly Andalusia and Extremadura). The second transportation was that related to the transfer of finished natural cork stoppers to the places where the bottles were sealed. The average length of transport was 471 km by lorry and 2,003.5 km by transoceanic freight ship. These values were calculated by taking into consideration all the sales of every company during 2008. Finally, the third transportation corresponds to that of the final disposal of the corks stoppers. It was considered that the landfill was located 50 km from the places where the cork stoppers were going to be used. This stage was included in order to determine their importance.

**Table 4.3. Inventory data to produce the FU (one million natural cork stoppers) in Southern Europe (Catalonia – Spain): main input flows.**

| Flows | Quantities average | Variability range (%) (1) |
|---|---|---|
| *Materials* | | |
| Raw cork (kg) | 13,812.3 | 74 - 150 |
| Water (m3) | 53.4 | 30 - 171 |
| Hydrogen peroxide (50%) (m3) | 0.1 | 20 - 176 |
| Paraffin (Kg) | 19.8 | 63 - 160 |
| Silicone (kg) | 10.1 | 60 - 149 |
| *Packaging* | | |
| Sulphur dioxide ($SO_2$) (kg) | 9.5 | 16 - 211 |
| HDPE (kg) | 48.0 | 83 - 104 |
| Aluminium (kg) | 2.5 | 0 - 400 |
| Corrugated cardboard (kg) | 377.5 | 82 - 106 |
| *Fuels* | | |
| Diesel oil (kg) | 1,955.8 | 22 - 238 |
| Butane (kg) | 1.3 | 00 - 400 |
| *Energy* | | |
| Electricity (MJ) | 27,821.1 | 47 - 163 |
| *Transport* | | |
| From the forest (km) - lorry | 741.30 | 3 – 169 |
| To winery (km) – lorry | 471.0 | 27 – 334 |
| To winery (km) - ship | 2,003.5 | 2 – 299 |
| To Final disposal (km) - lorry | 50.0 | Assumed distance |

(1) This variability represented the differences of material required to produce the natural cork stoppers FU depending on the company. The lowest percentage represented the company which used less quantity of inputs or transported from/to less distances.

## 4.3.2. Impact assessment of the production of natural cork stoppers in Southern Europe (Catalonia – Spain)

It was observed that different impacts were caused during the life cycle of the production of cork stoppers. Table 4.4 presents the environmental burdens and a variability range associated with the production of natural cork stoppers in the studied Catalan companies. As a particularity, it could be observed in table 4.4 that in the MAETP category 6,038,094.38 kg of 1.4 DB eq. were emitted. This considerable value was caused by life cycles of diesel oil consumption and electricity, and this would explain why some stages or processes had a significant impact.

**Table 4.4. Total environmental impact of natural cork stopper production in Southern Europe (Catalonia - Spain) and range of variability between different producers.**

| Impact Category | Units | Total Impact | Variability range (%) (1) |
|---|---|---|---|
| ADP | kg Sb eq. | 116.62 | 40-182 |
| GWP | kg $CO_2$ eq. | 10,947.02 | 51-157 |
| AP | kg $SO_2$ eq. | 101.10 | 56-184 |
| EP | kg $PO_4^{3-}$ eq. | 14.04 | 33-168 |
| ODP | kg CFC11 eq. | 1.79E-03 | 26-187 |
| POCP | kg $C_2H_4$ eq. | 13.74 | 38-158 |
| HTP | kg 1.4 DB eq. | 2,309.14 | 54-161 |
| TETP | kg 1.4 DB eq. | 47.70 | 59-159 |
| FAETP | kg 1.4 DB eq. | 833.29 | 64-155 |
| MAETP | kg 1.4 DB eq. | 6.04E+06 | 55-167 |

(1) This variability represented the variability of the impact depending on the company

The range of variability was an interesting indicator that measures the difference in the environmental impact of natural cork stoppers which were produced in one company or in another. As regards ADP, producing a natural cork stopper in the least favourable company increased the impact to 4.5 times that of producing it in the most favourable company. Besides, for each category a different range of variability exists because it depends on the substance and quantities causing the impact. For example, if a company used a greater quantity of a material that significantly contributes to one impact category than another, this would significantly increase its impact in that category and also the range of variability.

Results indicate that 10,947.02 Kg of $CO_2$ eq. were emitted for the FU; this means that for one unit of natural cork stopper weighing 3.7 g, 10.9 g of $CO_2$ eq. was generated during the production. If we consider that 1,400 million natural cork stoppers were produced in Southern Europe (Catalonia – Spain) during 2008, this means that a potential emission of 15,300 t of $CO_2$ eq. was produced by this industrial activity, and considering that this represented 10% of the world production we can extrapolate and estimate that 153,000 t of $CO_2$ eq. would be emitted if a similar technology was considered. Likewise, these emissions should be balanced by the carbon sink made by cork oak forests.

The range for the potential global warming category was 51-157%. This means that an individual natural cork stopper produced in one company represented an emission of only 5.5 g of $CO_2$ eq., while in another company 17.1 g of $CO_2$ eq. was emitted. This huge difference between producing the stoppers in one place or another demonstrated that some companies could increase their efficiency and introduce improvements in their production by simply applying the best available techniques, because other enterprises with very similar technology and location were producing corks that had less of an impact.

### 4.3.3. Impact assessment of the production of natural cork stoppers by stages in Southern Europe (Catalonia – Spain)

The analysis of the relative results could help to understand which of the production stages contributed more to the environmental impact of natural cork stoppers. Figure 4.2 shows the average results and the distribution of the environmental impacts per stage. It can be observed that the manufacturing stage of the natural cork stoppers was the stage which caused most of an impact in the life cycle for 8 of the 10 impact categories (ADP, GWP, AP, ODP, HTP, TETP, FAETP, MAETP), displaying a range of 34-65% of the total impact. Furthermore, in the other two categories, EP and POCP, the manufacturing stage was the stage with the second greatest impact (28-29%), while the transport from the forest was the stage with greatest impact with a percentage of 41% and 43%, respectively. Moreover, to a lesser extent in these categories and in MAETP, the transport from the forest was the stage with the second greatest impact, between 23-35% of the impact.

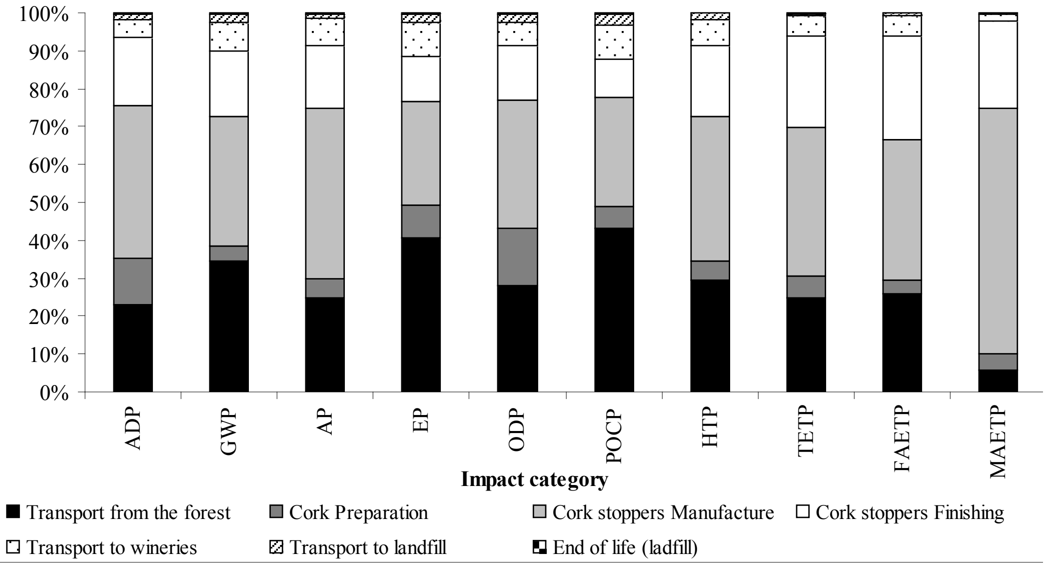



**Figure 4.2. Environmental impact assessment of natural cork stoppers in Southern Europe (Catalonia – Spain) by production stages.**

It can also be observed that the finishing stage of the natural cork stoppers represents a significant impact for the MAETP (22%). And also in some cases, the impact is approximately similar to that of the transport from the forest, as for example in FAETP, TETP or ADP. Preparation of the corks represents less than 8% of the impacts in all of the environmental categories, except for ADP in which it was 13% and ODP in which it was 15%.

On the other hand, the impact of the transport of waste to landfills and the disposal of the cork and the waste generated, were two stages with a lower impact, representing less than 3% in all the impact categories. And also, transport to the winery had an impact of between 3-9% of the total impact depending on the category analysed.

For GWP, the manufacturing and transport from the forest stages contribute to 34% of the impact, while the finishing stage represents 17% of the impact and transport to wineries represents 8%. Moreover, the rest of the stages together were responsible for less than 7% of the impact.

Table 4.5 contains the results without transportations; only considering the preparation, manufacture and finishing. Results are disaggregated in order to facilitate comparative analysis between operations. It was observed that the punching into cylindrical pieces and the size correction operations represented the most significant impact in the majority of the categories (GWP, AP, POCP, HTP, TETP, FAETP and MAETP), while the second boiling represented the biggest impact in terms of ADP, EP and ODP. These results indicate quite clearly that improvements in these operations rather than others are preferable due to their bigger impact.

**Table 4.5. Environmental impact assessment of the preparation, manufacture and finishing stages and substages in Southern Europe (Catalonia – Spain).**

| Impact categories | Units | Preparation[6] | | | | Manufacture | | | | Finishing | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Reception | First Boiled | Slabs Selection | Bundled of slabs | 2nd boiled - stabilization | Cut into strips | Punched into cylindrical pieces | Size correction | Washing - drying | Colouring | Stopper Chosen | Printing - Branding | Surface Treatment | Counting - Packaging | |
| ADP | kg Sb eq. | 0.31 | 13.57 | 0.59 | 0.17 | 26.31 | 1.57 | 10.02 | 8.91 | 5.54 | 5.95 | 1.91 | 1.01 | 1.71 | 4.67 | **82.25** |
| GWP | kg $CO_2$ eq. | 44.25 | 297.61 | 88.60 | 26.53 | 587.81 | 241.74 | 1,525.78 | 1,366.49 | 486.21 | 170.53 | 292.48 | 151.32 | 189.86 | 612.74 | **6,081.95** |
| AP | kg $SO_2$ eq. | 0.48 | 3.33 | 1.02 | 0.33 | 6.64 | 3.04 | 18.64 | 17.12 | 3.98 | 2.00 | 3.64 | 1.91 | 2.04 | 3.24 | **67.42** |
| EP | kg $PO_4^{3-}$ eq. | 0.05 | 1.04 | 0.07 | 0.01 | 2.02 | 0.13 | 0.97 | 0.74 | 0.37 | 0.46 | 0.17 | 0.08 | 0.10 | 0.47 | **6.69** |
| ODP | kg CFC11 eq. | 3.3E-06 | 2.6E-04 | 4.8E-06 | 8.0E-07 | 5.0E-04 | 7.4E-06 | 6.0E-05 | 4.4E-05 | 7.2E-05 | 1.1E-04 | 9.8E-06 | 5.2E-06 | 2.7E-05 | 3.9E-05 | **1.1E-03** |
| POCP | kg $C_2H_4$ eq. | 0.13 | 0.48 | 0.18 | 0.02 | 0.94 | 0.17 | 1.78 | 1.04 | 0.33 | 0.23 | 0.25 | 0.10 | 0.12 | 0.36 | **6.13** |
| HTP | kg 1.4 DB eq. | 8.87 | 84.94 | 18.91 | 6.16 | 167.06 | 55.97 | 343.42 | 315.14 | 127.01 | 46.16 | 67.09 | 35.14 | 44.00 | 109.81 | **1,429.65** |
| TETP | kg 1.4 DB eq. | 0.22 | 2.02 | 0.43 | 0.12 | 3.95 | 1.13 | 7.20 | 6.39 | 3.11 | 1.05 | 1.37 | 0.71 | 0.95 | 4.26 | **32.91** |
| FAETP | kg 1.4 DB eq. | 3.49 | 19.35 | 7.29 | 2.31 | 38.16 | 21.00 | 130.06 | 118.40 | 68.94 | 11.93 | 25.25 | 13.14 | 15.03 | 94.08 | **568.42** |
| MAETP | kg 1.4 DB eq. | 3.45E+04 | 1.07E+05 | 8.58E+04 | 3.26E+04 | 2.26E+05 | 2.95E+05 | 1.73E+06 | 1.65E+06 | 3.60E+05 | 1.04E+05 | 3.48E+05 | 1.85E+05 | 2.03E+05 | 2.02E+05 | **5.56E+06** |

[6] Cut of slabs is a handmade substage without loses of material because useless fork for natural cork stoppers production is derived as a by-product to agglomerate industry. For this reason, the environmental impact of this stage is virtually zero.

Subsequently, in this section, a wide perspective of the environmental impact of the different operations included in each stage will be assessed. The knowledge of which production processes had more of an impact in the life cycle and why would provide a decision criteria for enterprises to decide which areas of cork technology could be more researched and improved, from an environmental and cleaner production point of view.

## *Preparation stage: impact assessment*

The fact that this stage was mainly composed of different manual processes and the only technology involved was in the first boiling meant this stage caused a lower impact in the natural cork stopper production system.

The first boiling was the most impacting process out of the preparation stage, with an impact measuring between 41-97%, depending on the impact category. This was especially caused by the use of 554.8 kg of diesel oil in boilers (Figure 4.3). The other production processes in this stage represented a lower percentage. Likewise, the selection of slabs that exclude a part of the boiled cork was the process with the second highest impact, with an average of between 2-33%. The cutting of slabs is a manual operation without material loss because cork that cannot be used in natural cork stopper production is sent as a by-product to the agglomerate industry, and the environmental impact is virtually zero.

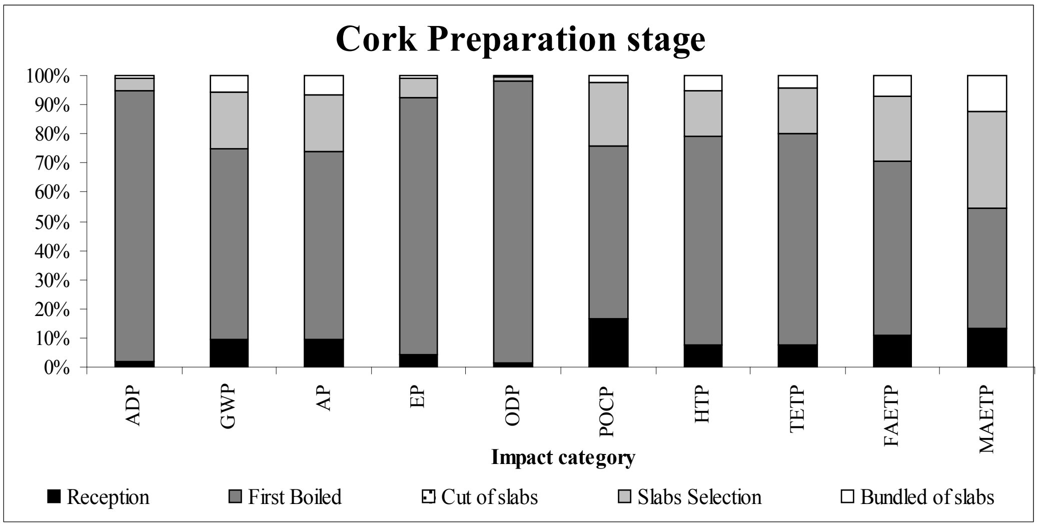



**Figure 4.3. Environmental impact of the preparation stage of cork slabs by production processes in Southern Europe (Catalonia – Spain).**

## *Manufacture stage: impact assessment*

As has been observed in the whole assessment of the natural cork stoppers, the manufacturing was the stage which caused most impact. The main contribution to the ADP, EP and ODP was the second boiling, with an impact percentage of about 52-82% depending on the category analysed (Figure 4.4). In this boiling also, the main contribution to the impact is the use of diesel oil in the boiler (1,072.1 kg).

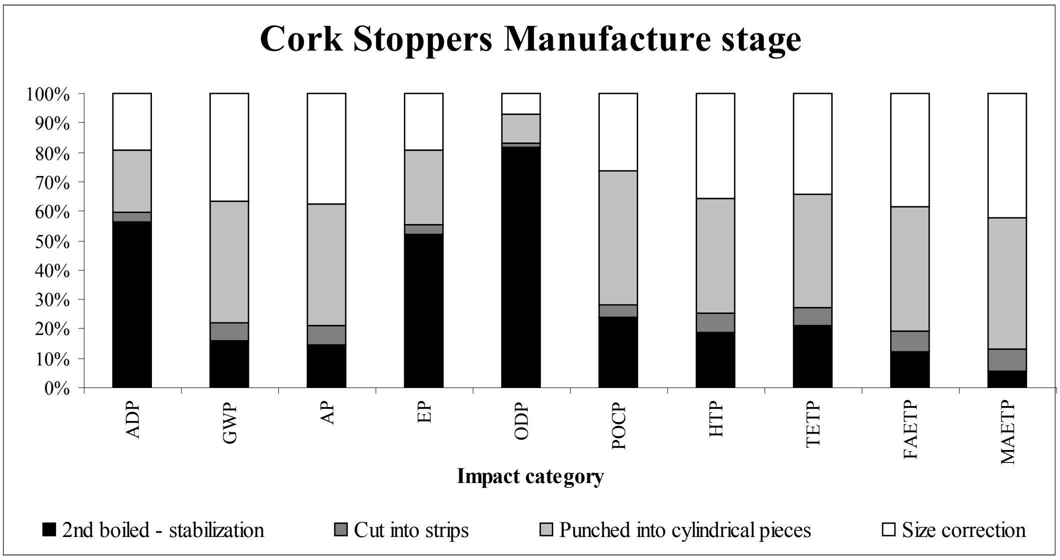



**Figure 4.4. Environmental impact of the manufacturing stage of natural cork stopper production in Southern Europe (Catalonia – Spain).**

In the other impact categories (GWP, AP, ODP, POCP, HTP, TETP, FAETP and MAETP), the process of punching the cork into cylindrical pieces causes most impact by the quantity of electricity consumed, between 39-44%, but the size correction had a similar impact in some cases. Finally, it could be considered that the minimum contribution was caused by cutting the cork into strips because this was a simple process done by a machine and with little cork loss.

Significant differences were observed between the different companies, because a natural cork stopper produced in one company or another could have a greater impact during manufacturing. While company A had an impact of 78% less than the average result, company C had an impact 128% greater than the average for ADP. Similar results were observed for the rest of the impact categories although the percentages vary depending on each category. As a result, only ADP, GWP and AP are shown in figure 4.5 because the same trend could be observed in the rest of the impact categories.

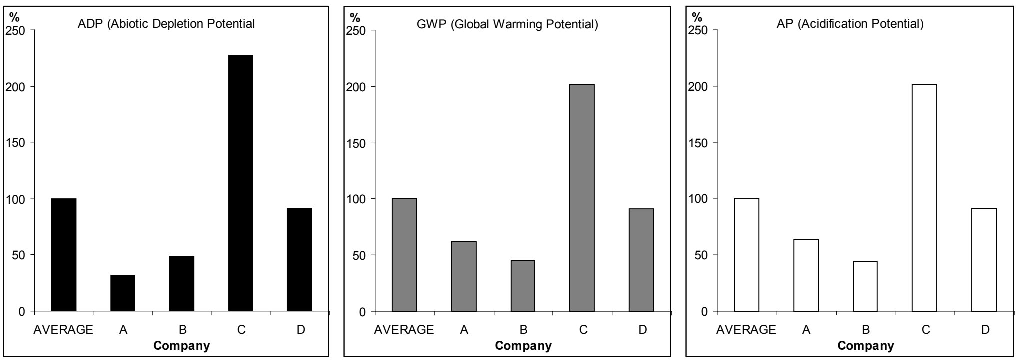



**Figure 4.5. Differences in the environmental impact of the manufacturing stage of natural cork stoppers depending on the producer company.**

### *Finishing stage: impact assessment*

As regards the finishing stage processes, it can be observed that the washing-drying process contributed the most in 4 impact categories: AP, POCP, HTP, MAETP, with 22-26%, due to the quantity of electricity consumed; while in ADP, EP, ODP the colouring was the process which made most of an impact, between 28-42% depending on the case, because of the use of diesel oil. As regards GWP, TETP and FAETP the counting and packaging were the processes which made the greatest impact, between 33-44% (Figure 4.6).

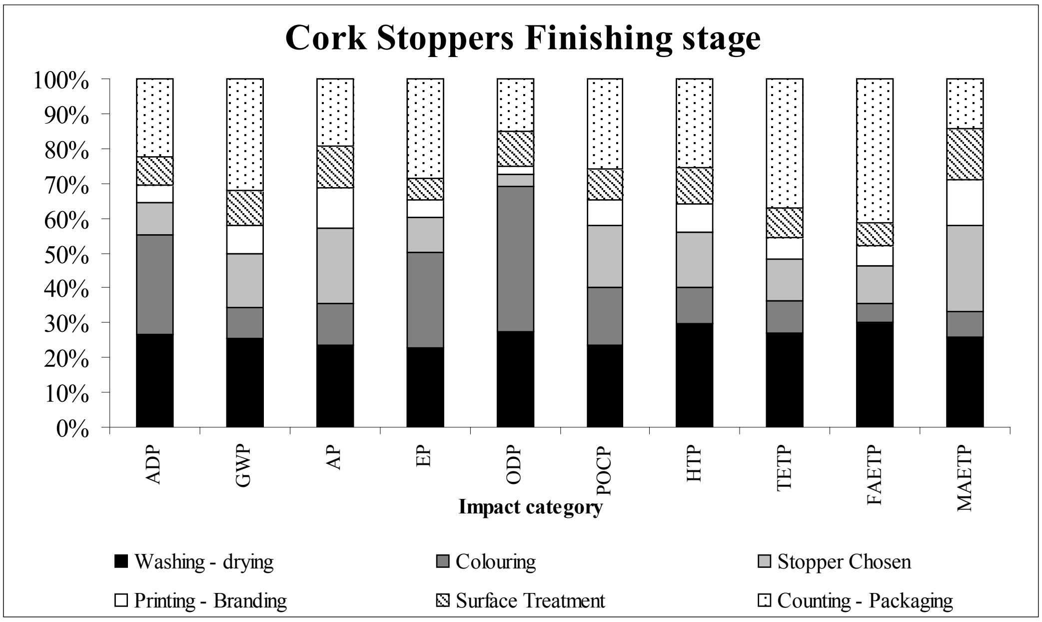



**Figure 4.6. Environmental impact of the finishing stage of natural cork stopper production in Southern Europe (Catalonia – Spain).**

The comparison of the average impact and the different companies reveals that there are differences between some impact categories for the finishing stage, while in others those differences were more reduced (Figure 4.7). For ADP, company B had 57% less of an impact than the average, while company C is clearly the company causing the greatest impact with 83% more than the average. The same occurred with the other categories. However, for example, company A caused a lower impact than average in the ADP (23% less), while it caused a greater impact in the GWP (17%). The same occurred with company D; in some cases the impact caused was lower than the average while at other times it was greater. This occurs because, depending on the combination of inputs, they can contribute more to one category than to others.

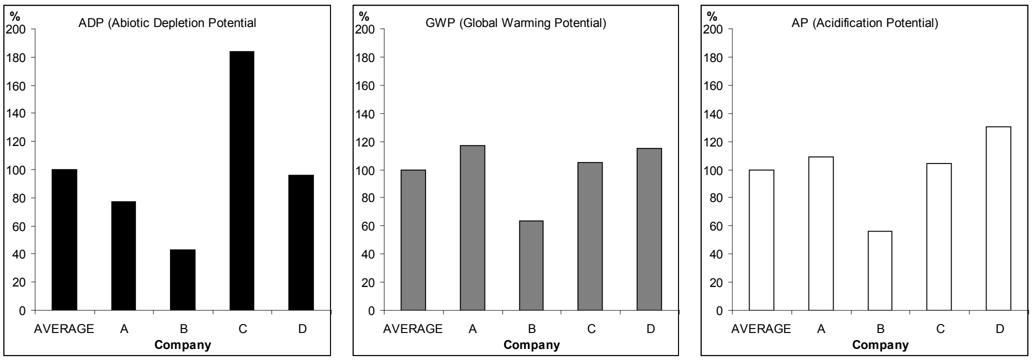



**Figure 4.7. Differences in the environmental impact of the finishing stage of natural cork stoppers depending on the producer company.**

## 4.3.4. Influence of the transport from the forest: location of the companies

In this section we analysed how the use of raw cork extracted on a local scale or imported from different distances could affect the current system, because this was the stage causing the second greatest impact and it was not associated with the technology used in the process. Moreover, it was interesting to assess how locating the companies closer to the extraction areas could minimise the environmental impact of the production of natural cork stoppers.

As regards the GWP category, a company that used raw cork from a nearby forest caused the lowest environmental impact, while those companies that manufacture their cork stoppers from raw cork imported or transported for long distances caused the greatest impact (Figure 4.8). A similar fact could have been observed if the other categories had been analysed.

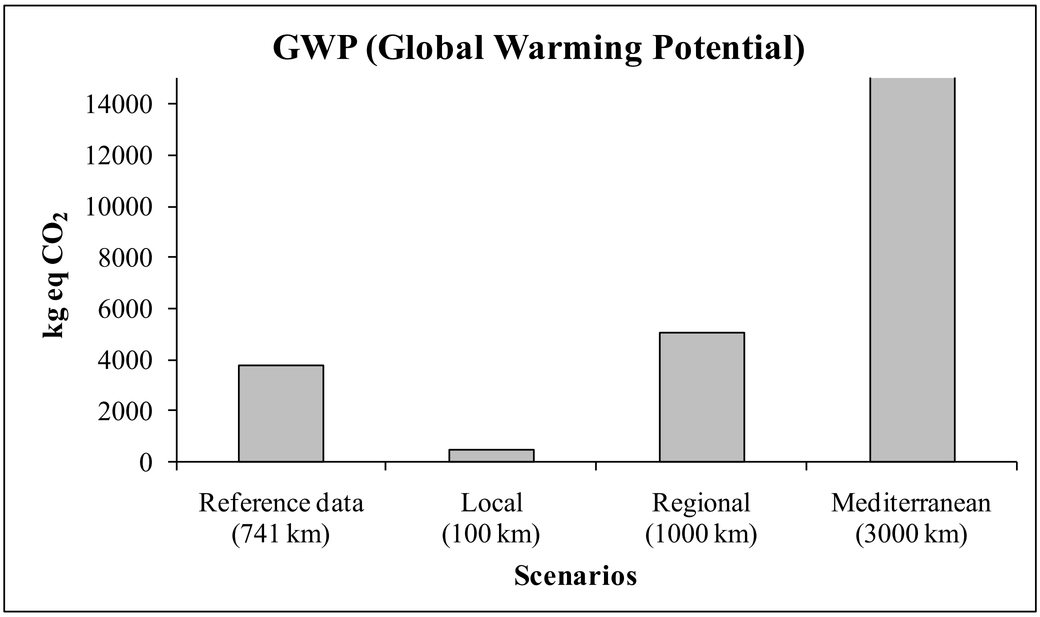



**Figure 4.8. Sensitivity analysis of the transport of raw cork from the forest for the GWP category considering the results (reference data), and 3 different distances of the locations of the forests.**

$CO_2$ eq. emissions would increase or decrease according to the scenario considered. As was observed in the previous results, a natural cork stopper produced at an average distance of 741 km from the forest (reference data) and weighing 3.7 g, emitted 10.9 g of $CO_2$ eq., while if the cork was transported from local providers, at a distance of 100 km, the total emission would be of 7.7 g, 30% less than the average scenario. Moreover, if the forest was located in a regional scenario such as the Iberian Peninsula (1,000 km) or in a Mediterranean scenario (3,000 km) the $CO_2$ eq. emissions would be of 12.3 and 22.4 g respectively. This represented an increase of about 13% in the impact for regional transport and more than twice the impact for distances of 3,000 km.

It can also be observed that the transport directly affects the main system (Figure 4.9), and for those systems in which the cork was imported from long distances, their impact was greater than that of the production of natural cork stoppers. For those systems it is more important to optimise the logistics than to implement measures in order to obtain technological improvements in the production of natural cork stoppers.

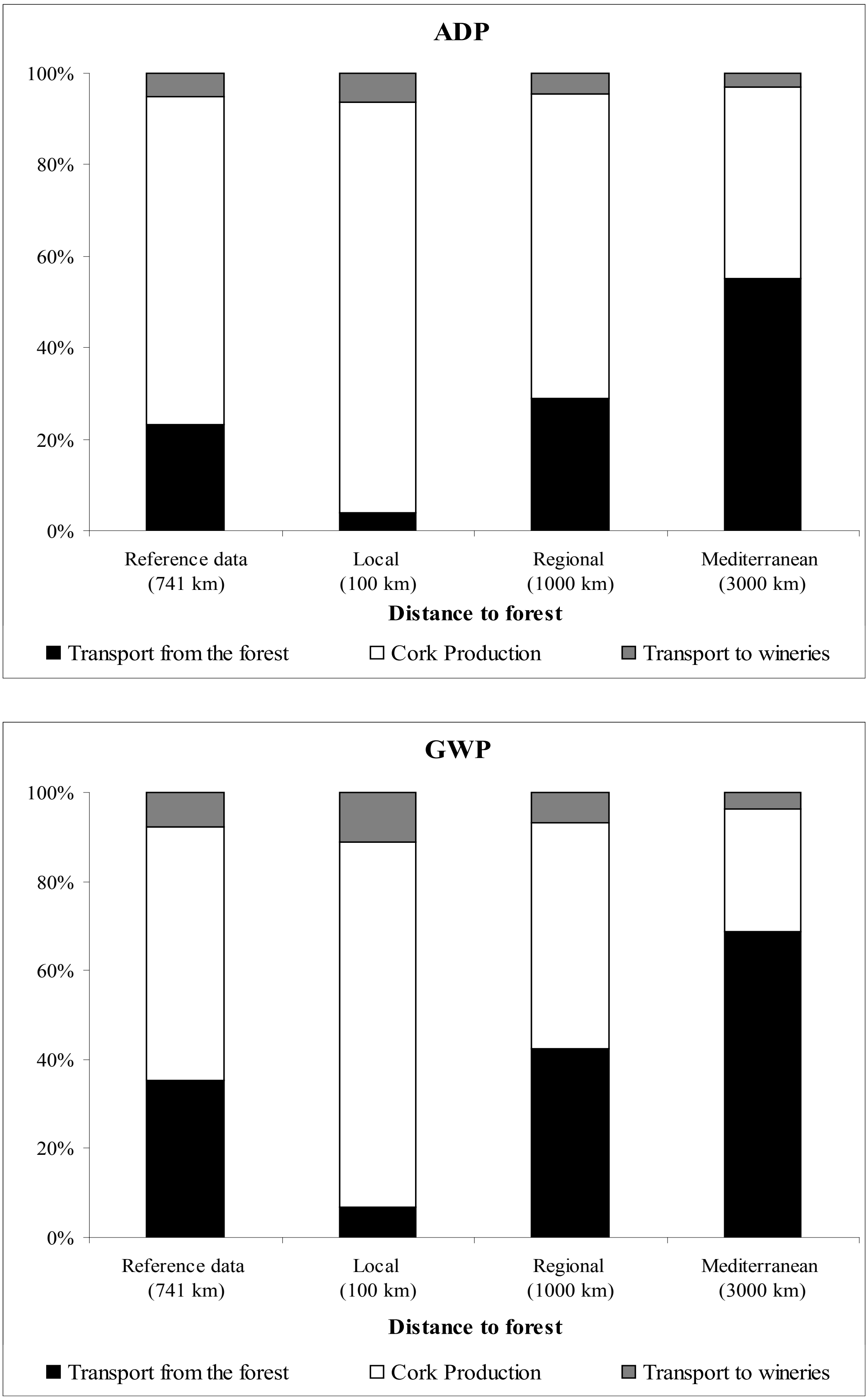



**Figure 4.9. Differences in the main system of the LCA of the transport stage considering the results (reference data) and 3 different distances of the locations of the forests.**

If an analysis of the influence of the transport to wineries was carried out, the same trend as that of transport from the forest would be found. But in this case, differences would be less significant because in this stage the quantity of material transported was lower than at the beginning due to by-products generated during the process. Furthermore, in this case transoceanic freight ship transports should be considered in order to analyse how very long distances could affect the main system. The impact of all the transports must be considered when the production of a bottle of wine is studied.

## 4.4. Conclusions

- The natural cork stopper industry is a traditional sector made up of different stages: transport from the forest, preparation of cork slabs, manufacturing of natural cork stoppers, finishing and distribution to wineries.
- A lot of reproduction cork was required to produce one unit of natural cork stoppers; more specifically, 3.7 times the final mass was required. This generated a lot of by-products that were used to produce other agglomerated products. Furthermore, a significant amount of raw materials and energy was required to produce one million natural cork stoppers, main input flows were: 13.8 t of raw cork, 53.5 $m^3$ of water, 1,955.8 Kg of diesel oil, 27,821 MJ of electricity, 136.2 l of hydrogen peroxide, 19.8 kg of paraffin and 10.1 kg of silicone.

Based on the results obtained, the following particular outcomes can be stated about the impact assessment:

- In table 4.4, reference data of natural cork stopper production in Southern Europe (Catalonia – Spain) were provided as a first approximation to best available techniques (BAT). It was found that 10.9 g of $CO_2$ eq. were emitted in the production of one single stopper that weighed 3.7 g.
- Due to the fact that the manufacturing stage caused the greatest impact in the life cycle of natural cork stoppers, between 34-65%, in terms of ADP, GWP, AP, ODP, HTP, TETP, FAETP and MAETP, companies must give priority to improving this stage. In particular, the operation of punching the cork into cylindrical pieces, the size correction and the second boiling. This could be done by optimising the resources and especially by reducing and/or replacing energy consumption: electricity and diesel oil.
- It was stated that transport directly affects the whole cycle of the product and for those systems in which the cork was imported from long distances, their impact could be greater than that of industrial production. A good environmentally-friendly alternative to improve the impact of the sector is the integration between forestry and the cork industry, reducing the distances to transport reproduction cork.
- According to the results, the main short-term improvements that could be introduced in the production of natural cork stoppers were: (1) implementing the best available technologies in the most critical manufacturing processes,

(2) substituting non renewable sources of energy, and (3) using local raw cork and resources. Moreover, on a long term basis, companies could be located at a closer distance to the forests. This innovative approach enabled a more ecological and sustainable production to take place, increasing the companies' competitiveness and reducing their production and operation costs.

- Clear differences between the production of a natural cork stopper in one enterprise or in another were observed: depending on the impact category a stopper could be produced causing twice or three times the environmental impact. This means that traditional industries in the sector had the opportunity to improve and optimise their processes from an environmental point of view, with the current technology. Moreover, differences could be attributed to the total quantity of resources used (table 4.3) and especially the transports, but also to differences in the production process.

Chapter 5

# ENVIRONMENTAL ANALYSIS OF CORK GRANULATE PRODUCTION IN SOUTHERN EUROPE (CATALONIA – SPAIN)

# 5. Environmental analysis of cork granulate production in Southern Europe (Catalonia – Spain)

This chapter is based on the following paper:

- **Rives, J., Gabarrell, X., Fernandez-Rodriguez, I., Rieradevall, J. Environmental analysis of cork granulates production in southern Europe (Catalonia - Spain). Submitted on January 2011 to *Resources, Conservation and Recycling.***


## Abstract

Cork is a natural and renewable material harvested mainly in the Western Mediterranean area. Apart from natural cork stoppers and discs, the most important product of the cork sector is cork granulate, because it represents a solution for the large quantities of wastes generated during natural cork industry production and during forestry activities. Cork granulates have not yet been studied from an environmental perspective, while this ecomaterial could substitute other non-renewable and more impacting materials such as petroleum derivates. This study presents the environmental analysis of the production of two different cork granulates: white and black, following the life-cycle assessment (LCA) methodology, and all the operations after forest management were analysed, from the extraction of the resources to the use of these intermediate products. Research also tried to identify which operations during production contribute most to potential environmental impact. Inventory data was collected from three representative local producers that all use standard technology.

Regarding environmental burdens, trituration and classification and sieving were the operations which contribute most to the environmental impact of granulate production; together representing between 90-97% of the environmental burdens for the studied categories. It was also stated that 35% of the initial raw material that enters the system became dust during the production of both types of granulates. Cork dust is a potential material that can be use as a fuel substituting other non-renewable sources of energy such as diesel oil or electricity. However, it was observed that the use of these wastes as energy source was still in an incipient point of implantation.



## Keywords

Cork granulate, ecomaterial, environmental impact, life cycle assessment (LCA), Mediterranean

## 5.1. Introduction

Cork oak (*Quercus suber L.*) is a medium-sized, evergreen oak from the Fagaceae family characterised by a bark of up to 15 cm thickness that could be extracted without endangering the tree as it regenerates over time. It has been a natural part of Mediterranean forests for many thousands of years, and over the centuries humans have found various applications for suberised bark because of some of the unique properties associated with cork: it is a natural and renewable material, impermeable to liquids and gases, compressible, flexible, has very low thermal conductivity, has energy-absorbing capacity and an apparent lack of chemical reactivity, etc. [76].

Cork oak forests contribute to different environmental services such as carbon dioxide fixing, hydrology regulation, prevention of desertification and preservation of wildlife. The cork sector could contribute to mitigate climate change in the Mediterranean area and also, to protect biodiversity. It represents a model of sustainability between human activity and natural resources. Cork as a natural, renewable and ecomaterial could be used as a raw material substituting other non-renewable materials such as petroleum derivates.

Due to unique environmental and climatic conditions, cork oak only grows commercially around the western Mediterranean area. At present, the cork forest area in the world is about 2,277,700 ha, and more than 55% of this area is concentrated in the Iberian Peninsula. Besides, the annual average production of this area is about 245.400 tonnes: 82% of the world production [18]. In Catalonia, it is estimated that 63,000 ha of cork oak woodlands exist [68]. In the future the percentages of cork oak production could change because in northern Africa forests are quite young relative to the forests in Portugal and Spain, due to a cork forestation programme established by French colonial administration when the area was under their control [19].

The cork sector is traditional and it is mainly constituted by two basic systems: the forestry system which consists of cork raw material extraction and forestry management operations, and the industrial system that is the part where the raw material is turned into different products. The industrial system could be also divided into two production groups: the natural cork industry and the granulate-agglomerate industry. The difference between them lies in the fact that natural cork products are made up of solid cork with a minimum transformation of the raw material, while granulate-agglomerate products are composed by crushed and consequently joined cork. Another difference is that most of the economical benefits of the sector were generated by natural cork products. The most representative products from natural cork are the natural cork stoppers for still wine, and the natural cork discs that are an intermediate product that will be assembled with cork agglomerates to manufacture technical stoppers, while the basic product of granulate-agglomerate lines is the granulate, that it is an intermediate product used to produce many products: the body of technical stoppers, pads, boards, floorings, shoe leathers, insoles, insulated panels and so on [22].

## 5.2. Cork sector: wastes and by-products

The cork sector is a craft and part of a very traditional business network that has tried to adapt to available technologies over the years. All the actors involved in the sector have tried to optimise the use of cork by connecting waste flows from one process into raw materials for other products [22] or into energy sources for other processes [186, 187].

Cork granulates are a by-product that can be defined as a raw material made from forestry and industry cork wastes, which their size must be between 0.25 - 8 mm, and which their specific weight must be between 55 - 75 kg/m$^3$ [184]. In principle the granulate industry can be divided basically into two types: white cork granulate and black cork granulate.

White cork granulate by-products are mainly intended to alimentary uses such as stoppers for wines, beers, champagnes, ciders etc., and for this reason a pretreatment or preparation is required in order to clean the raw material before processing it to meet the health requirements of the final product.

Black cork granulate is intended to non alimentary uses such as insulator panels, flooring, decoration, so on. In these cases, cleaning is not required. White cork granulate has a higher market price that black, and for this reason companies prefer to produce white. Despite, white cork granulate being preferable for the production of stoppers, it can be used for other applications.

Cork granulates are generated from forestry and industry cork wastes. Forestry wastes comprise different kinds of raw materials such as virgin cork[7], second cork[8], little pieces of reproduction cork[9], reproduction planks with defects, cork of tree branches, cork of fired trees etc.,, while, wastes from the natural industry comprises raw materials from (a) the preparation of natural cork products, (b) natural cork stopper production (pieces of cork resulting from the process of cutting into strips process, pieces of punched strips, rejected stoppers etc.), and (c) natural disc production: pieces left from cutting into strips, the cork's back layer and the belly layer generated in lamination, pieces left from punched out cork slices and rejected discs. Other sources of material could also be used to produce cork granulates such as recycled cork products , but at the moment systems of collection and recycling of these products are only occasional initiatives due to the difficulty in collecting this material from consumers.

The first objective of the cork industry is to produce natural cork products, because they are the most profitable [73, 177]. This fact can be observed in Table 5.1, where the two main cork forest resources were analysed. It can be stated that reproduction cork is the raw material with the highest price per kg, and it can

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[7] Virgin cork is those raw material generated because of the extraction of the first periderm of the tree, it presents deep fractures and a deformed structure. It is a cork obtained when the tree is between 35 and 40 years old.

[8] Second cork is generated after the second extraction and it contains deep fractures. Sometimes a small part of this could be used as reproduction cork.

[9] Reproduction cork is the cork from the third extraction onwards which represents the best quality raw material; is mainly intended to natural cork stopper production. However, only those planks with sufficient thickness will be destined for natural cork stopper production.

even be observed that 97.3% of the total value of a tonne of the cork in the forest corresponds to this.

**Table 5.1. Prices and values analysis of cork raw materials in the forest in 2008.** ***Source: prices based on [18].***

| Types of materials | Quantity of resource generated (%) | Price per kg (€) (2) | Costs of extraction per kg (€) (3) | Value of a tonne of raw material (€) (4) | Value of the resource from the total (%) |
|---|---|---|---|---|---|
| Reproduction cork | 86.5 | 2.07 | 0.26 | 1790.5 | 97.3 |
| Forestry wastes (1) | 13.5 | 0.37 | 0,26 | 49.9 | 2.7 |
| Total | 100 | - | 0,26 | 1840.4 | 100 |

(1) Forestry wastes consider virgin cork, second cork, fragments of cork, and other raw cork materials.

(2) The price of forestry wastes was averaged from the prices of virgin raw cork and pieces of cork

(3) This costs were accounted in the price

(4) Considering the quantity of each raw material

Although the market is clearly dominated by the natural cork stopper industry, the production of cork granulates is also important as the generation of granulates/agglomerates provides an outlet for a large amount of residual flows. More than 70% of the raw material that enters natural cork stopper production, is converted to industrial wastes or low economical value by-products [157]. It seems that the granulate industry originated in response to the need for cork waste management in order to optimise the raw material and minimise management costs.

# 5.3. Justification and research objectives

Natural products such as natural cork stoppers have been studied previously by our group [157] and it was found that the huge amounts of cork that were wasted in the life cycle of the natural cork stoppers represented a raw material for the granulate-agglomerated industry and a way to reuse the material. Moreover, other institutions have carried out research from an environmental perspective, analysing the potential environmental impact of natural cork stopper production [90, 91, 140] and also about some cork agglomerate applications [77, 188], but not on cork granulates. Research will be of interest to all the actors involved in the cork sector: institutions, forestry owners, industries and consumers.

Environmental performance of granulates is important because although the product with the highest added value is the natural cork stopper, more than 75% of the raw material harvested in the forest will sooner or later send to manufacture cork granulate. This means that cork granulation is a potential way to take advantage of waste as a by-product that could be recycled to generate raw materials for other applications postponing the end of the life of the material. Furthermore, it is important to carry out research on cork wastes and by-products to show how resources with a low economic value could become a means to improve the environment and a way to generate economic benefits.

The objectives were to quantify the environmental impact of producing cork granulates and identify the operations in the industry cycle that most contribute to them. Results on the environmental performance of granulates will represent an initial approximation about a natural, renewable and Mediterranean material that can be used as a raw material for multiple products, and that could substitute non-renewable resources, while the detection of the most pollutant operations will provide interesting information about which aspects of production causes most pollution and need to be improved from a technical and an environmental perspective. The results will support data about cork granulates and will allow comparison with other non-renewable raw materials. As there is no official best available techniques (BAT) reference document for cork granulates manufacturing, this research could be a first approach.

## 5.4. Methodology

The SETAC (Society of Environmental Toxicology and Chemistry) has been involved in increasing the awareness and understanding of the concept of life cycle assessment, and the methodology has rapidly developed into an important tool for authorities, industries, and individuals in environmental sciences.

The ISO 14040 regulations [109] establish that LCA can assist in: (a) identifying opportunities to improve the environmental performance of products at various points in their life cycle, (b) informing decision-makers, (c) the selection of relevant indicators of environmental performance, (d) and marketing. The four basic steps of the assessment procedure followed were: (1) goal and scope definition, (2) Life cycle inventory (LCI), (3) Life cycle impact assessment (LCIA) and (4) Life cycle interpretation [120, 127, 137].

### 5.4.1. Goal and scope definition

The purpose of the research was to quantify and analyse the production of white and black cork granulates from an environmental perspective. Also, the research was focused on the detection of the production processes that most contributes to the overall impact of the intermediate product in order to give a criterion to manufacturers to improve production. Two gate-to-gate studies were carried out, one for white cork granulate and one for black cork granulate. Although comparison between both cork granulates could be interesting, they could not be compared because they were used to manufacture different products with different functions. According to ISO standards; products with different functions cannot be compared, for this reason each granulate production process will be presented separately and comparison between them will not be carried out.

For both case studies, a tonne of the final product was selected as a functional unit (FU), with cork particles ranging from 0.25 to 8 mm. The granule size of the final product could change depending on customer preferences, but similar results have been found. Particles above 8 mm were reprocessed because they are too big to generate agglomerates of quality, while particles below 0.25 were considered dust and a waste for the cork granulate systems that could only be used as an energy source or as a filling agent (mixed with glues) for the worst quality cork stoppers called often natural colmated cork stoppers. But the use of dust to manufacture agglomerates or other products was difficult as the very small particles have a very high specific area and then require large amounts of glue which is not economically viable.

## 5.4.2. System description

Two different systems were analysed: the white cork granulate production system and the black cork granulate production system. The limits of both systems covered the complete life cycle of granulate production, and can be observed in Figure 5.1 and 5.2. The systems included (1) raw materials required for cork granulate production, (2) energy sources, (3) water consumption, (4) and transport of raw materials.

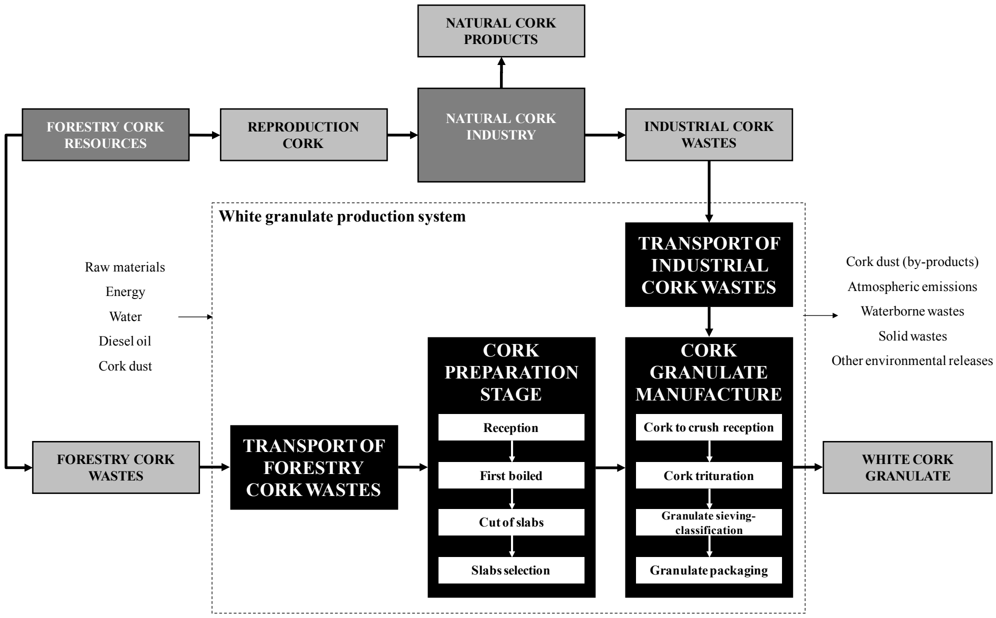



**Figure 5.1. Definition and boundaries of the white cork granulate production system studied including the main processes involved.**

### *White cork granulate production system*

The white cork granulate production system started in the forest, where the raw cork was extracted and classified into two parts: the reproduction cork that will be sent to the natural cork industry and the forestry cork wastes directly intended for the granulate industry. After going to the natural cork industry and after generating products, the large amounts of industrial waste generated will be introduced into the white cork granulate production system.

In our study system, it was found that the waste industry flow represented 80% of the raw material, while the remaining 20% was originated in the forest. However, if we consider different percentages of wastes from both origins, the same quality product will be obtained. Besides, a sensitivity analysis will be carried out analysing how the origin of the material could affect the results.

For forestry cork wastes a transport distance of 50 km was considered because distances from cork oak forests and the cork granulate industries in Catalonia were on a local scale. For industry wastes, a 50 km transport distance was also estimated as the distance between the natural cork industries and granulate cork industries ranged from 1 - 70 km depending on the exact location of each factory. However, a sensitivity analysis of the transport was also considered at the end of the study. This local transport was also associated with the low value of the by-product, because the transport of waste over long distances could make it more expensive and less profitable.

After transport, preparation stage took place for forestry cork wastes, while this stage was not required for industrial cork wastes as they are already prepared in the natural cork industry and allocated to those activities. The preparation stage consists of different operations in order to guarantee the traceability of raw cork and to ensure that the wedges and all cork bark with yellow stain have been segregated [184]. During this stage raw cork was selected and some pieces of raw cork were eliminated because of unpleasant defects such as green cork, yellow spots or clayed cork. Furthermore, the main characteristic activity of this stage is the boiling in clean water at 100ºC for 1 hour, in order to clean the cork, extract water-soluble substances, and to improve cork flexibility and elasticity. In this way, the cork is stabilised, and then those parts that are too big are cut and selected again.

Following this, the manufacturing of granulate takes place. First, the raw cork goes through a crush reception operation to guarantee the quality of the raw material, and the correct storage to preserve the cork from alterations. Subsequently the trituration or grinding process is carried out. This operation consists basically of breaking up the pieces of raw cork into small particles of between 0.25 - 8 mm. Then these particles are sieved using densimetric tables. The separation by density classes allows for sorting out heavier particles that are reprocessed. Fine particles with dimensions lower than 0.25 mm are removed as dust along the process and sometimes used as an energy source. This dust represents about 35% of the initial raw cork. Finally, the different granulate fractions were packaged depending on user specifications.

### *Black cork granulate production system*

The initial material was originated in the forest and that preparation stage was not required. In this research it was considered that industry wastes introduced in the system were negligible compared with forestry wastes, because it is preferred that natural cork industry wastes be used to manufacture white cork granulate because of its higher added economical value. However, it was completely suitable to produce black cork granulates from industry wastes. The transport distance of forestry wastes was also considered to be 50 km and the manufacture stage was estimated to be similar to white cork granulate production. Figure 5.2 presents the system study for black cork granulate production.

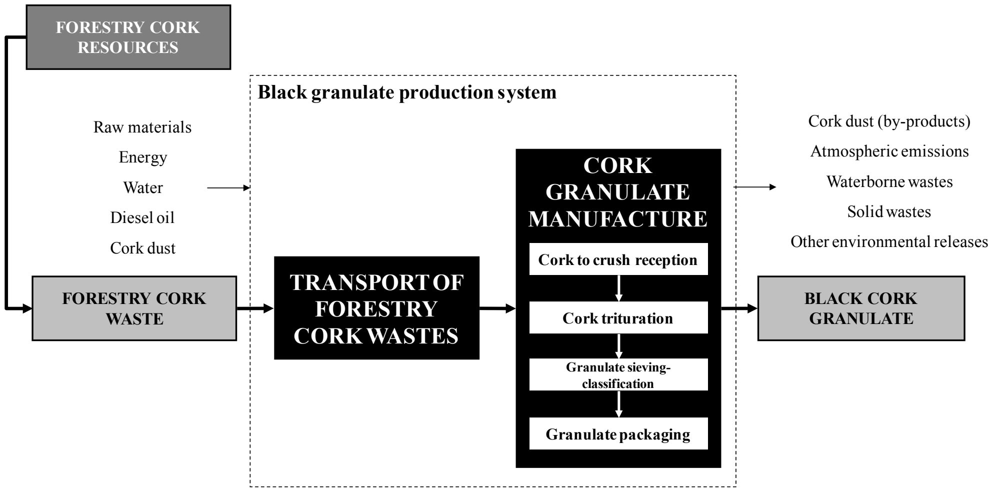



**Figure 5.2. Definition and boundaries of the black cork granulate production system studied including the main processes involved.**

## 5.4.3. Considerations

Forest management was excluded from the system because the objective of the research was the improvement of the cork granulate industry from an environmental point of view.

Administrative, laboratory and business operations were excluded from the production impact because they depend on particular situations, because they represent a very insignificant impact compared to granulate production and also because the aim of the study was the improvement of the granulate production and not the particular practices of certain enterprises. Furthermore, due to the long useful life of industrial buildings and machinery and the high quantity of production generated, these elements were not considered as they had an insignificant effect on the operation scale.

Wastewater and the combustion of cork dust as a fuel were excluded from the study due to the lack of data available about these emissions. It was observed that companies are not obliged to measure the quality of the water after the boiling, and only in a few cases do they measure some basic parameters such as pH, COD, total nitrogen or suspended materials. For combusted cork dust, it was considered that biomass use for energy generation is considered "carbon neutral" over its life cycle because combustion of biomass releases the same amount of $CO_2$ as was captured by the plant during its growth [189]. Therefore, it must be pointed out that this source of energy was renewable and that it avoided the environmental impact of using other non-renewable sources of energy, especially electricity.

## 5.4.4. Quality and data origin

Fieldwork was the first step of the research. In Catalonia, only six enterprises concentrated on the production of granulates in 2009, and three of these companies were selected to perform the study. These companies were small or medium enterprises that have adopted ISO 9001 standards and that have quality recorded data. They also include all the granulate cork production and they have implemented industry standard technology. One of them was involved solely in the granulate production (white and black), while the others also produce other type of cork products.

The production system was established according to the International Code of Cork Stopper Manufacturing Practice [184]. A questionnaire to collect inventory data for granulate production was prepared, including energy and material flows, emissions and wastes. All the local data were obtained directly through the questionnaires that were filled out by the environmental industry experts of each company, and following this, the data was verified by the Catalan Cork Institute, a cork research institution of reference. During the whole data collection process, the authors helped the industries to understand and complete the questionnaire. Data required referred to machinery characteristics, rates of production, materials flows, water consumption, transport of raw materials, movement between production processes and so on. All of them supplied data about their production in 2009 and all the information was obtained from records at each company or in those cases that it had not been registered it was measured directly. After obtaining individual data for the white cork granulate production of every enterprise, averages of the three production systems were calculated and thus a sectorial inventory was achieved. No important differences among the three companies were observed. In the case of black cork granulate, production was estimated considering the same technology available as for white cork granulate.

Moreover, based on the experience of a previous study about natural cork stoppers of the research group [157] other indirect data of the sector could be obtained and processed. To complete the life cycle inventory (LCI), the Ecoinvent database v2.2 was used [190].

## 5.4.5. Allocation procedure

In this case, the systems were quite complex due to the fact that some inputs are a by-product of other cork products, and as such, production was collateral and unavoidable. For this reason the burden allocation procedures should be accurately defined. Although, expanding the system boundary to include all the products affected in the cork sector would be the best approach, it was unfeasible in terms of data collection because several different flows were involved in the overall sector. Allocation is one of the most discussed methodological issues in LCA because of the complexity involved, especially for open-loop recycling systems [191]. Although guidelines and handbooks exist about LCA methodology and its application, the attribution of environmental burdens to a product under study is an ambiguous task that can rely on subjective assumptions and choices [192].

The cut-off method was applied in this research. According to this relatively easy allocation, environmental burdens should be assigned to the system that is directly responsible for them [129, 136, 191]. According to cut-off method, industry cork wastes enter the cork granulate production system without any environmental burden because all their impact was attributed to natural cork products because such production was the objective of the sector and because of the much higher added value of natural products compared to granulated-agglomerated products. Then, for the white cork granulate production system, non environmental burdens were allocated to industrial wastes because they was allocated to the life cycle of natural cork products [157].

### 5.4.6. Software and LCA methodology

The software Gabi 4.3 [193] was used to quantify the environmental impact of cork granulate production. Only the obligatory classification and characterisation phases defined by ISO 14040 regulation were performed [109]. With this, the CML 2001 impact assessment method [127] was used. All the impacts were allocated to the production of cork stoppers. The impact categories considered were: Abiotic Depletion Potential (ADP), Global Warming Potential (GWP 100 years), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Layer Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), Human Toxicity Potential (HTP), Terrestric Ecotoxicity Potential (TETP), Freshwater Aquatic Ecotoxicity Potential (FAETP) and Marine Aquatic Ecotoxicity Potential (MAETP). In addition, an energy indicator based on cumulative energy demand (CED) [190] was used to calculate the direct and indirect amounts of energy consumed.

## 5.5. Results and discussion

First, this section presents an approach to the cork sector organisation in Catalonia. Next, the life cycle inventory and the environmental impact assessment of white and black cork granulates production will be presented, considering the methodology described earlier. Finally, some sensitivity analyses were carried out to observe the influence of some parameters.

### 5.5.1. Cork sector organisation approach

It was stated that practically all the raw cork extracted from the forests were transformed into some product, by-products or at least were used as an energy source. The same happened with all the wastes generated during the production of different natural cork products. One could understand the cork sector as a cyclic system where all the materials were used various times until they can only be used as a renewable energy source. Figure 5.3, shows an approach to the cork sector organisation and the main cork flow exchanges between subsystems in Catalonia (Northern Spain).

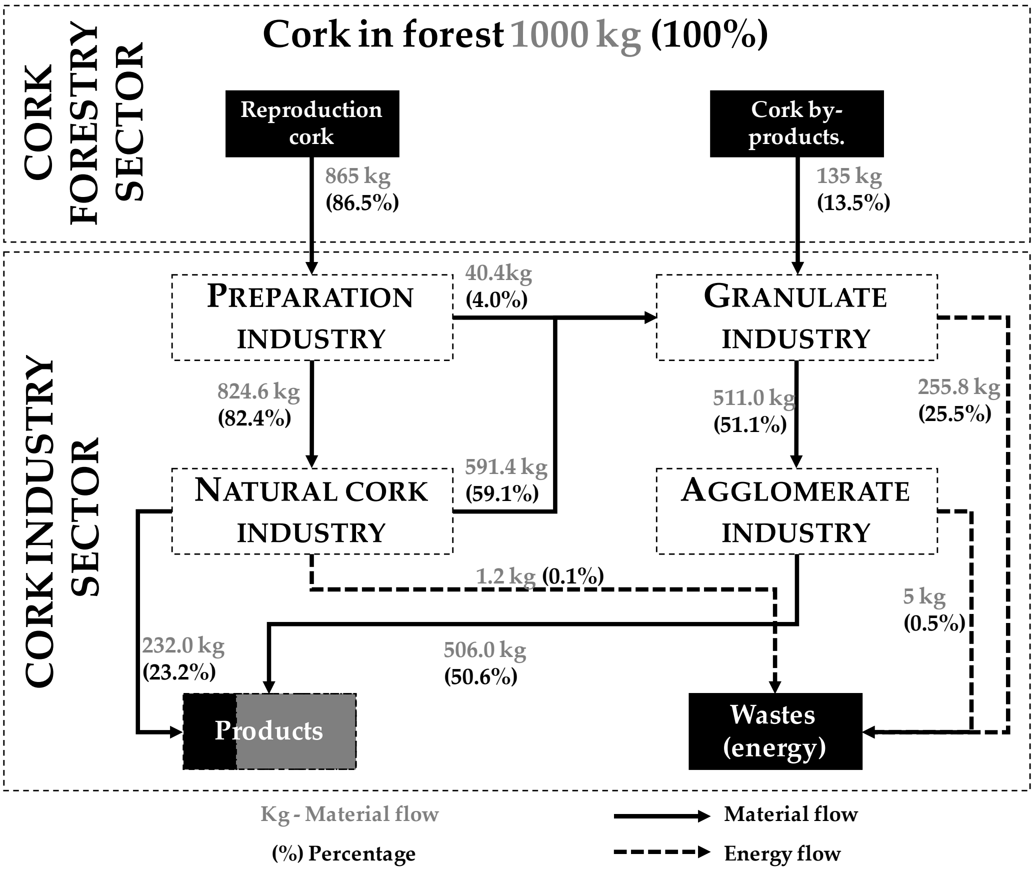



**Figure 5.3. Approach to the cork sector organisation in Catalonia: estimation of cork flows exchanges between subsystems. (Percentages were calculated from an initial 1000 kg of raw cork in the forest).**

It can be observed that from the starting point of 1000 kg of raw cork extracted in the forest, 865 kg corresponded to reproduction cork while 135 kg were forestry wastes considering virgin and second cork, little pieces of cork, planks with defects, so on. These figures were calculated and averaged from the analysis of 5 exploitations in Catalonia. Each one located in a different extractive area and comprising surface area ranging between 260 and 750 ha, and a range of extraction between 19 and 96 t of raw cork yearly. All these exploitations were located within 50 km of the cork granulate industries.

From the 1000 kg of the initial raw cork in the forest, only 23.2% will be transformed into natural cork products after passing through the preparation industry and natural cork industry. This means that although 865 kg really enter the natural cork product production system; significant amounts of cork waste or by-products will be generated and consequently recycled into cork granulates, concretely more than 70% of the material that enters this system will be later sent to the granulate-agglomerate industry.

It could also be stated, that from the initial 1000 kg of raw cork, 506.0 kg will result in agglomerated products. Here, it must be pointed out that despite the evident importance of the economical benefit from natural cork products (Table 5.1), agglomerate products are economical alternatives to optimise the large amount of wastes generated by natural cork industries. Besides this, granulate-agglomerate products represent an important help to cover costs and even to generate profits.

### 5.5.2. Life Cycle Inventory of white and black granulate production (LCI)

This section describes the inventory data needed to produce a tonne of white cork granulate or a tonne of black cork granulate; the FU established. The main average flows are calculated and reported in Table 5.2.

**Table 5.2. Inventory data to produce the Functional Unit (FU): a tonne of granulate.**

| INPUTS | | |
|---|---|---|
| **Flows** | **White cork granulate** | **Black cork granulate** |
| ***Materials*** | | |
| Raw cork – forestry origin (kg) | 309.2 | 1,538.0 |
| Raw cork – industrial origin (kg) | 1,236.6 | 0.0 |
| Water (l) | 193.9 | 0.0 |
| ***Energy sources*** | | |
| Diesel oil (kg) | 2.2 | 0.0 |
| Electricity (MJ) | 1,327.0 | 1,325.8 |
| Cork dust (kg) | 8.6 | 0.0 |
| ***Transport*** | | |
| Lorry from the forest (km) | 50.0 | 50.0 |
| Lorry from industries (km) | 50.0 | - |

| OUTPUTS | | |
|---|---|---|
| **Flows (1)** | **White cork granulate** | **Black cork granulate** |
| ***Commercial product (UF)*** | | |
| Cork granulate (0.25 – 8 mm) (kg) | 1000.0 | 1000.0 |
| ***Wastes*** | | |
| Cork dust (particle <0.25 mm) (2) | 530.4 | 539.0 |
| Cork with unpleasant defects (3) | 15.4 | 0.0 |

(1) Particle above 8 mm were recirculated and reprocessed

(2) Cork dust was a waste of the production and it could be used as energy source

(3) Cork with unpleasant defects was a waste of the white granulate production but it could be used for black cork granulate production

One of the main facts that can be stated from white cork granulate production inventory was that 1,545.8 kg of raw cork were required to produce a tonne of product. This is because during the production an important quantity of dust was produced (530.4 kg). This fraction of cork was mainly removed by suction along the processing operations, and it could be used as combustion fuel. In fact, the quantity of dust cork produced was higher, 539 kg, but a small part of this material; 8.6 kg were used as a renewable source of energy for the boiling operation during the preparation stage. Some authors have pointed out that the higher heating values for cork dust is about 37.66 $MJ \cdot kg^{-1}$ [187], and between 24.7-30.4 $MJ \cdot kg^{-1}$ [186]. It was stated that the substitution of other more impacting sources of energy such as diesel oil and electricity was an incipient fact only carried out in the boiling operation of preparation stage of white cork granulate production. It was stated as being an important potential of environmental improvement in this field, and it was observed that industries are going to implant and develop this technology in the near future.

In the case of black cork granulate, 1,539 kg of raw cork was required to produce a tonne, while 539 kg of cork dust were generated. In this case, apart from cork the unique flow required to produce the granulate was electricity, because this product did not require the preparation stage, and practically all the operations were physical transformations such as mixing, trituration, classification and so on.

The means of transport considered for both products and from both origins, forestry and industry, was road. We took into consideration the production, maintenance and disposition of the vehicle, the construction and maintenance of the roads and diesel consumption [194]. Although a local transport distance of 50 km was considered for the main production system, in the sensitivity analysis the distance would be tested in order to assess how this parameter could affect the results because at the present, some flows of raw cork are imported from Portugal, and in the future if granulate demand grows considerably, raw cork could be imported from emerging areas of cork extraction such as Northern Africa. It was detected that forestry residues were not transported long distances because due to the limiting effect of the low price of granulates.

### 5.5.3. Impact assessment of white cork granulate production

It was stated that during the life cycle of white cork granulate production, different potential environmental impacts were created. The main environmental burdens associated with its production in the studied companies can be found in Table 5.3. During the production of white cork granulate; 0.77 kg of $CO_2$ eq. was emitted per kg of product and 4.55E+04 MJ eq. was used. However, it must be considered that carbon fixed by cork oak forests was not taken into account. Most of the emissions were generated because of the use of electricity during production.

**Table 5.3. Potential environmental impacts associated to a tonne of white cork granulate production in the studied companies in Catalonia (Northern Spain).**

| Impact Category | Units | White cork granulate |
|---|---|---|
| ADP | kg Sb eq. | 5.05 |
| GWP | kg $CO_2$ eq. | 772.14 |
| AP | kg $SO_2$ eq. | 6.40 |
| EP | kg $PO_4^{3-}$ eq. | 0.44 |
| ODP | kg CFC11 eq. | 4.43E-05 |
| POCP | kg $C_2H_4$ eq. | 0.55 |
| HTP | kg 1.4 DB eq. | 159.86 |
| TETP | kg 1.4 DB eq. | 3.67 |
| FAETP | kg 1.4 DB eq. | 45.25 |
| MAETP | kg 1.4 DB eq. | 7.33E+05 |
| RAD | Daly eq. | 1.02E-05 |
| CED | MJ eq. | 4.55E+04 |

Figure 5.4 shows the distribution of the impacts by the production process for white cork granulate. It could be stated that trituration was the operation with most impact of all the impact categories and also for the CED indicator, contributing an overall impact of between 59% and 69% depending on the category analysed. Classification and sieving also contributed considerably to the total impact; between 26% and 36%. The operations that formed the preparation stage: reception; boiling, cutting of slabs and slab selection all together represented at most 3% of the impact.

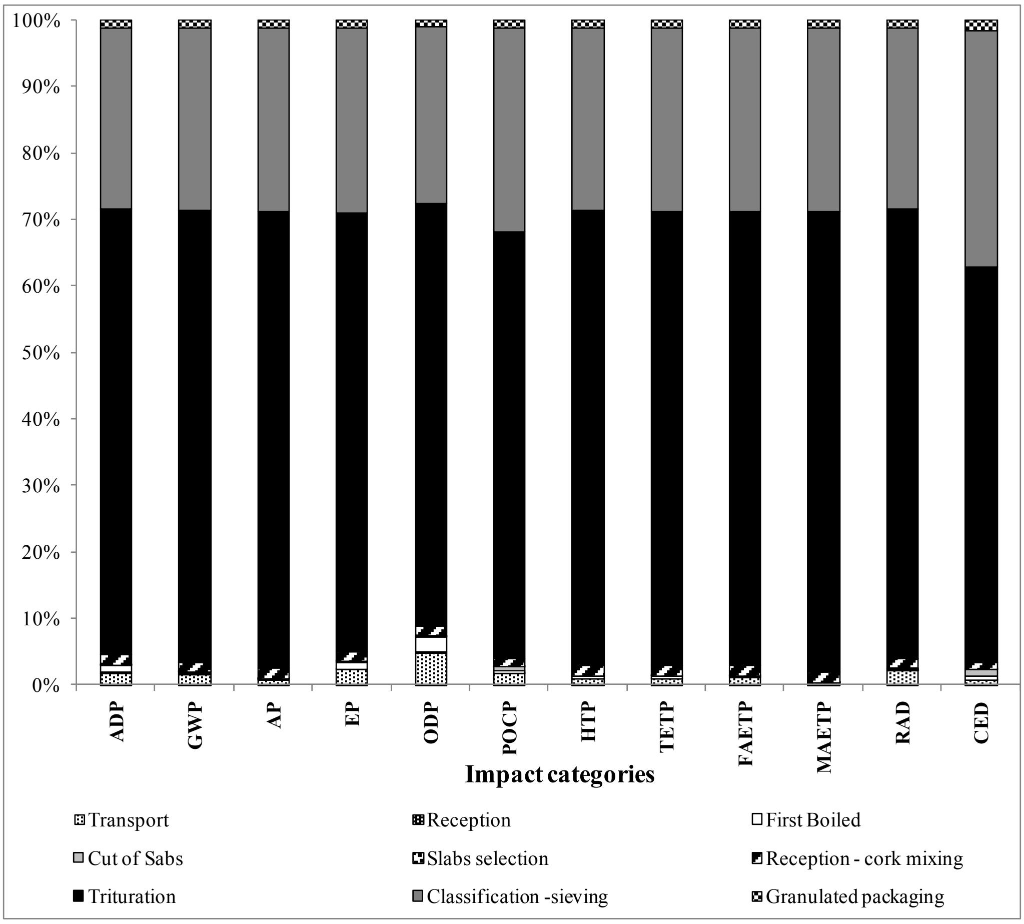



**Figure 5.4. Environmental impact assessment of white cork granulate production in the studied companies by operations.**

The transport of the raw cork in a local scale (50 km) represented less than 2% of the impact in all the impact categories studied. Only for ODP, was the percentage any higher (5%). At the end of this paper, a sensitivity analysis of this aspect will be analysed in order to study how this aspect could change the absolute and relative results.

From the analysis of the results, it is clear than an improvement in technology at the preparation stage or in some of these operations would mean only a small change in the environment, while improvements in trituration, classification and sieving operations would lead to a considerable reduction in the environmental impact of the product. It could also be found that technical improvements in terms of the local transport would hardly reduce pollution at all.

## 5.5.4. Impact assessment of black cork granulate production

This subsection analysed the potential environmental impacts associated with the production of black cork granulate. The machinery considered was the same to produce white cork granulate. Table 5.4 presents the results for this product. It was obtained that 0.77 kg of $CO_2$ was originated per kg of product and the CED indicator was 4.52E+04 MJ eq. The greater part of the environmental impact was due to the electricity required to recycle the waste material into a new intermediate product.

**Table 5.4. Potential environmental impacts associated to a tonne of black cork granulate production in the studied companies in Catalonia (Northern Spain).**

| Impact Category | Units | Black cork granulate |
|---|---|---|
| ADP | kg Sb eq. | 4.99 |
| GWP | kg $CO_2$ eq. | 770.33 |
| AP | kg $SO_2$ eq. | 6.38 |
| EP | kg $PO_4^{3-}$ eq. | 0.43 |
| ODP | kg CFC11 eq. | 4.32E-05 |
| POCP | kg $C_2H_4$ eq. | 0.54 |
| HTP | kg 1.4 DB eq. | 159.10 |
| TETP | kg 1.4 DB eq. | 3.66 |
| FAETP | kg 1.4 DB eq. | 45.13 |
| MAETP | kg 1.4 DB eq. | 7.32E+05 |
| RAD | Daly eq. | 1.02E-05 |
| CED | MJ eq. | 4.52E+04 |

Analysing the results by processing operation, finds that trituration contributed between 60 and 69% of the environmental impact depending on the category considered, while the classification and sieving operations contribution was between 27 and 36%. Transport contributed to less than 5% of the environmental impact in all the impact categories. For black cork granulate production, the operations that might be prioritised for technical and environmental improvements are trituration, classification and sieving because together they are responsible for over 92% of the impact in all the categories studied. Results by operation can be observed in Figure 5.5.

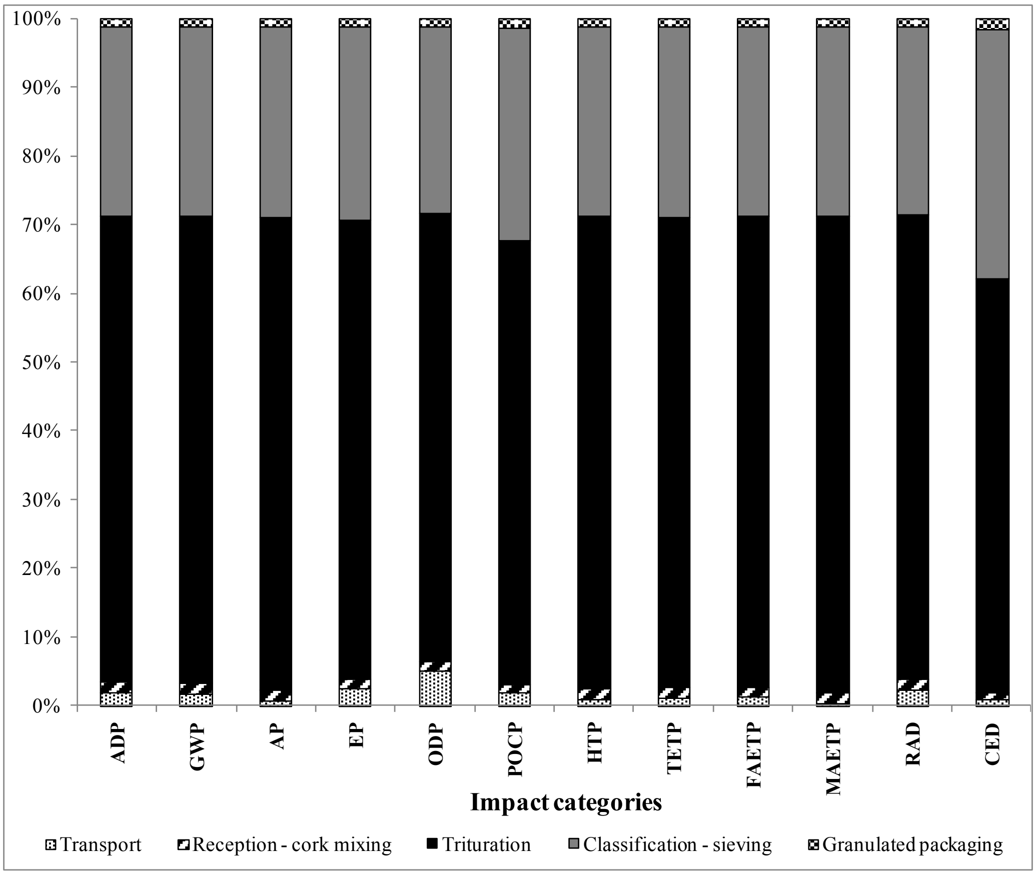



**Figure 5.5. Environmental impact assessment of black cork granulate production in the studied companies by operations.**

## 5.5.5. Sensitivity analysis

In this section two considerations are analysed in order to identify how the results obtained can change if we modify some conditions of the systems. The first sensitivity analysis studied whether the use of industrial or forestry wastes increases or decreases the environmental impact obtained and the second sensitivity analysis studied the initial transport of the waste products.

### *Origin of raw cork material (industrial or forestry wastes)*

Here, only white cork granulate production was analysed as it was assumed that black cork granulate production was made completely from forestry wastes. Moreover, if black cork granulate was generated from industry wastes, the same results as those obtained are found because to manufacture black cork granulate it is not necessary to prepare the material and consequently the same treatment is done for wastes of both origins. For white cork granulate, the origin of the wastes is important because those coming from forestry activities must be prepared before manufacturing the granulate, while those wastes coming from the natural cork industry need not be cleaned because they have been prepared previously.

Here 3 scenarios for white cork granulate production were proposed:

- Scenario 1: This was the reference scenario from which the results were calculated. It was considered that 20% of the material was produced from forestry wastes and 80% from industry wastes because this data was obtained during the inventory analysis.

- Scenario 2: All the initial raw material was industrial waste and it enters the system directly at the manufacturing stage.
- Scenario 3: All the material to produce the white cork granulate was from forestry wastes and all the material needs to be prepared.

Results for the 3 scenarios can be observed in table 5.5 in percentages. At a simple view, it can be observed that differences considering one or another scenario were not very significant for most of the categories. For example, the potential environmental impact associated to ADP ranges from 4.99 to 5.29. If we consider scenario 1 as the reference, the difference in the impact for this category was at most 4.7%. The same trend was detected with all the impact categories, with a difference also less than 4%. Only for ODP the difference was a little more significant about 9.7%. One could state that the origin of the raw material affects the results very little because it only affects the preparation stage and the environmental impact of the operations of this stage was very low as was commented earlier. Results of scenario 2 were at least 2.5% less than for the reference scenario because only the preparation stage is deleted because this stage was relevant to natural cork products.

**Table 5.5. Potential environmental impacts of the production of a tonne of white cork granulate, considering three different scenarios of wastes origin (percentage results fixing scenario 1 as 100.0%)**

| Impact Category | Units | S1 | S2 | S3 |
|---|---|---|---|---|
| ADP | kg Sb eq. | 100.0 | 98.8 | 104.7 |
| GWP | kg $CO_2$ eq. | 100.0 | 99.7 | 101.1 |
| AP | kg $SO_2$ eq. | 100.0 | 99.7 | 101.3 |
| EP | kg $PO_4^{3-}$ eq. | 100.0 | 98.9 | 104.5 |
| ODP | kg CFC11 eq. | 100.0 | 97.6 | 109.7 |
| POCP | kg $C_2H_4$ eq. | 100.0 | 99.2 | 103.0 |
| HTP | kg 1.4 DB eq. | 100.0 | 99.5 | 102.0 |
| TETP | kg 1.4 DB eq. | 100.0 | 99.6 | 101.4 |
| FAETP | kg 1.4 DB eq. | 100.0 | 99.7 | 101.2 |
| MAETP | kg 1.4 DB eq. | 100.0 | 99.8 | 100.8 |
| RAD | Daly eq. | 100.0 | 99.7 | 101.0 |
| CED | MJ eq. | 100.0 | 99.1 | 103.8 |

S1 – reference scenario with 20% of forestry wastes and 80% of industrial wastes

S2 – All the wastes from industry

S3 – All the wastes from the forest

### *Effect of transport on the system*

In the study an average local transport distance of 50 km was considered for both types of cork wastes. However, in this section, we wanted to analyse the importance of this parameter in the results because sometimes raw cork materials could come from other areas on a regional or national scale such as Southern Spain or Portugal. Moreover, the possibility of providing Catalonia with cork resources from emergent cork production areas such as North Africa could be assessed, and for this reason one of the proposed scenarios is *international* transport. Only a sensitivity analysis for white cork granulate production need be presented because the same trend would be observed for black.

It must be taken into account that at the moment Catalonia is transporting reproduction cork from Southern Spain and Portugal. However the impact of this resource must be allocated to natural cork products and not to granulates because the objective and the profit of the industry is the former. The sensitivity analysis of transport was intended to assess how changes in the transport of forestry wastes and industry wastes could affect environmental impacts associated to granulate production.

To simplify, 4 different transport scenarios were compared. For all of them, road transport by lorry was considered. Other intermediate scenarios could be analysed and compared such as scenarios where one of the wastes flows was transported on a local scale and the other was on a regional, national or international scale, but the same trend would be found as that which was observed. The proposed scenarios are:

T1 - Local scenario: transport of 50 km for both flows. Reference scenario

T2- Regional scenario: transport of 300 km for both flows

T3 - National scenario: transport of 1000 km for both flows

T4 - International scenario: transport of 3000 km for both flows

As it could be stated in Table 5.6, transport was a parameter that directly affected the overall results. The effect was notable for international transport, where its impact could double or triple depending on the category considered. For a regional scenario the increase in impact represented between 1% and 22% depending on the considered category, while for national scenario, the environmental impact increased between 4% and 85%.

**Table 5.6. Potential environmental impacts of the production of a tonne of white cork granulate, considering four different scenarios of wastes transport (percentage results fixing scenario 1 as 100.0%)**

| Impact Category | Units | T1 | T2 | T3 | T4 |
|---|---|---|---|---|---|
| ADP | kg Sb eq. | 100.0 | 108.8 | 133.6 | 204.4 |
| GWP | kg $CO_2$ eq. | 100.0 | 108.1 | 130.6 | 195.1 |
| AP | kg $SO_2$ eq. | 100.0 | 103.4 | 112.9 | 140.2 |
| EP | kg $PO_4^{3-}$ eq. | 100.0 | 110.7 | 140.8 | 226.8 |
| ODP | kg CFC11 eq. | 100.0 | 122.4 | 185.0 | 364.0 |
| POCP | kg $C_2H_4$ eq. | 100.0 | 106.7 | 125.6 | 179.5 |
| HTP | kg 1.4 DB eq. | 100.0 | 104.3 | 116.5 | 151.1 |
| TETP | kg 1.4 DB eq. | 100.0 | 105.0 | 119.1 | 159.3 |
| FAETP | kg 1.4 DB eq. | 100.0 | 105.5 | 121.0 | 165.2 |
| MAETP | kg 1.4 DB eq. | 100.0 | 101.2 | 104.5 | 113.8 |
| RAD | Daly eq. | 100.0 | 110.8 | 141.1 | 227.5 |
| CED | MJ eq. | 100.0 | 102.4 | 109.0 | 127.8 |

T1 - Local scenario: transport of 50 km for both wastes. Reference scenario

T2- Regional scenario: transport of 300 km for both wastes

T3 - National scenario: transport of 1000 km for both wastes

T4 - International scenario: transport of 3000 km for both wastes

As it can be observed in Figure 5.6, if the most extreme transport scenario (3000 km) is analysed in depth, it could be stated the importance of this stage in the whole life cycle of the product. In these circumstances, transport was the operation that had most overall impact on most categories: ADP, GWP, EP, ODP, POCP, FAETP, RAD and also for CED indicator. Only for AP, HTP, TETP and MAETP did the trituration operation represent the main impact of the system. From an environmental perspective, and considering the sensitivity analysis of transport, international transport of raw cork material was not advised.

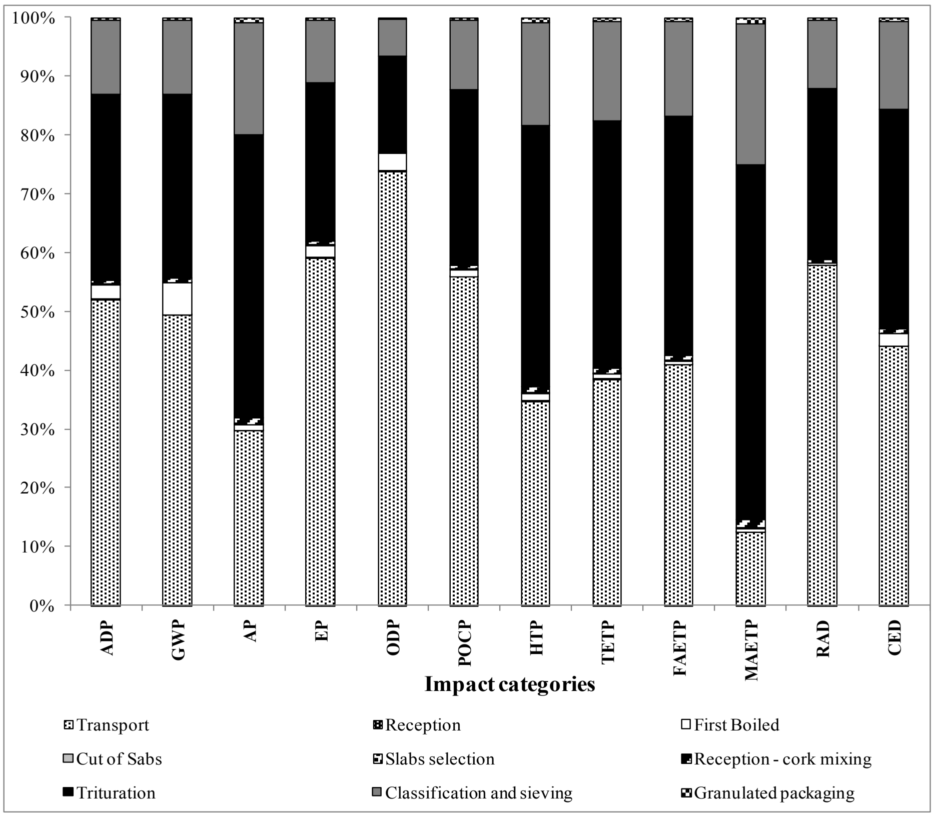



**Figure 5.6. Sensitivity analysis of the transport for white cork granulate. The variation of relative results when considering a scenario involving long distance transport by road (3000 km).**

# 5.6. Conclusions

- Granulate-agglomerate industry is a solution to manage the large amount of forestry and industry wastes generated because more than 50% of the initial harvested raw material in the forest will soon or later became a granulate due to the nature of the cork. Cork granulates are an example of a raw material optimisation system because all the cork flows that were a waste in one point could became granulates and used as resources for other products or at least used as a renewable energy source substituting other more impacting non renewable energy sources.
- In Tables 3 and 4, reference data of white and black cork granulate production in Southern Europe (Catalonia – Spain) are provided as a first approximation to best available techniques (BAT). It was found that 770 kg of $CO_2$ eq. were emitted in the production of a tonne of black cork granulate, and 772 kg were emitted during the production of a tonne of white cork granulate.
- During the production of a tonne of white cork granulate large amounts of electricity were required to produce a tonne of product, 1,327 MJ. Moreover, 539 kg of dusts were generated, while only 8.6 kg of them was used as energy during boiling operation. This means that this biomass could be used as a source of renewable energy substituting other more impacting sources of

energy such as electricity. It was stated that the use of these cork dusts as energy is still incipient and only some companies of the cork sector have started to implement this cleaner production practice for water boiling operations due to high machinery costs. It must be more implanted, more developed and also, more researched in the next future. An alternative to face the investment costs that could be studied in the future is the installation of a collective cork sector plant to generate electricity from cork dusts or in a larger scale a biomass plant in the region to take advantage of them as well as other sources of biomass.

- For white cork granulate production, trituration is the operation that contributes most to the potential environmental impact with between 59 - 69% for all the categories. Classification and sieving contributed between 26 - 36% depending on the category analysed. On the other hand, transport of the cork wastes and all the preparation operations together represented less than 4% of the impact for all the impacts categories, except for ODP that represented 7%.
- Environmentally, in black cork granulate, trituration was the most polluting operation causing between 60 - 69% of the impact for all the impact categories as well as the CED indicator, while classification and sieving caused between 27 - 36% of the environmental impact.
- The sensitivity analysis of the origin of the initial raw material, forestry or industrial, indicated that this parameter will not significantly modify the results. At most, if all the raw material proceeds from forest the environmental impact will increase by between 1 and 5% for all the impact categories, except for ODP where the increase would be of 10%. In the case of all the wastes coming from industry, the results decrease between 0 and 2.5%. This is because the only difference for both sources of raw material was that forestry wastes must be prepared and this stage is done manually and represents little impact.
- The transport of the raw cork material was a parameter that at present affects the system very little due to the fact that all the initial raw material transports occur on a local scale. However, increase in distance would result in a significant increase in the environmental impact. Local transport is preferable and for this reason the situation of industries near the extractives zones are advised.

# Chapter 6

# ENVIRONMENTAL ANALYSIS OF THE PRODUCTION OF CHAMPAGNE CORK STOPPERS

# 6. Environmental analysis of the production of champagne cork stoppers

This chapter is based on the following paper:

- **Rives, J., Fernandez-Rodriguez, I., Rieradevall, J., Gabarrell, X. Environmental analysis of the production of champagne cork stoppers in southern Europe (Catalonia - Spain). Submitted on March 2011 to *Journal of Cleaner Production.***

## Abstract

Champagne cork stopper is a product made basically from cork that is a natural and renewable resource extracted from cork oak forests in western Mediterranean regions. Each stopper is constituted by an agglomerated cork body and two natural cork discs. In 2009, 60% of the worldwide champagne cork stopper was produced in Catalonia, due to the importance of cava, champagne and other sparkling wines in neighbouring areas. The aim of the research was provide environmental reference data on the champagne cork stoppers production, and identify the industrial stages and operations that represented the greatest impact. This research was carried out using life cycle assessment (LCA) methodology, and five of the most representative producers were analysed. The system considered all the processes involved in the production after the forest management stage and one million champagne cork stoppers were taken as a functional unit (FU).

Results pointed out that 53,886 kg of $CO_2$ eq. were emitted to produce the FU. It was observed that champagne cork stopper manufacture stage represented between 57 and 67% of the environmental impact depending on the category. Specifically, between 25-47% of the environmental impacts associated to this stage was caused by the body agglomeration operation, and between 21-29% was caused by the gluing of discs. On the other hand, some of the production stages such as the transport of raw cork and intermediate products, cork slab preparation or end of life stages represented a very small part of the total environmental impact of the product, less than 2%. Furthermore, it was observed that a champagne cork stopper produced by the most impacting company presented a higher impact, between 10-27% above the sector average, depending on the impact category; while the least impacting company presented between 12-32% less impact. These differences indicate that some companies can improve their production by substituting technology and production practices that some of their competitors have already put in place.

## Keywords

Cork agglomerate, champagne cork stopper, environmental impact, life cycle assessment (LCA), Mediterranean, natural cork disc.

## 6.1. Background, scope and aim

Cork is a raw material, obtained from the outer bark of the cork oak. The bark can be stripped off from the stem without endangering the tree and later the tree regrows new cork bark. This natural and renewable material is exploited in the western part of the Mediterranean region because of the restricted distribution of the species in this area [26]. In 2009, 55% of the worldwide cork oak forest were situated in the Iberian Peninsula, and also 82% of the worldwide raw cork material was harvested in these area [18]. The availability of cork as a raw material caused the cork industry to be developed and concentrated in this area.

Cork products are often categorised as natural cork products or as granulate-agglomerated products depending on the used cork. Natural cork products, especially natural cork stoppers and discs, are those product made up by solid cork and they are the first aim of the cork industrial production because of their high economic profitability [69]. It is for this reason that reproduction cork, which is the best cork and has a notable thickness, is primarily intended for these uses. One striking feature of the cork industry is that mass yields of natural cork products are low, only 25-30% of the prepared cork will became a product, while the remaining 70-75% will became industrial waste that will be later recycled to manufacture cork granulates and subsequently transformed into agglomerated products [22, 157]. Maximising yields of the natural cork industry seems to be very difficult because cork present imperfections and irregularities due to its nature. However, cork granulates corresponded to an environmental and economical strategy to make profit from those important and unavoidable amounts of collateral cork industrial waste generated.

Cork stoppers are the most representative product of the cork sector. A wide variety of cylindrical stoppers exist: natural cork stoppers and natural cork stopper multiparts, agglomerate stoppers without natural cork discs, agglomerated stoppers with one or two discs at the end, agglomerated stoppers with one disc at the top and one at the bottom. Besides, many forms and sizes exist such as conical stoppers, holed stoppers, crowned stoppers, bevelled stoppers, so on, and also different combinations of agglomerated cork and natural parts are to be found. Moreover, there are few mixed stoppers that are part cork and part other materials (wood, aluminium, plastic etc.) [25]. In Figure 6.1, an overview of the cork products is presented.

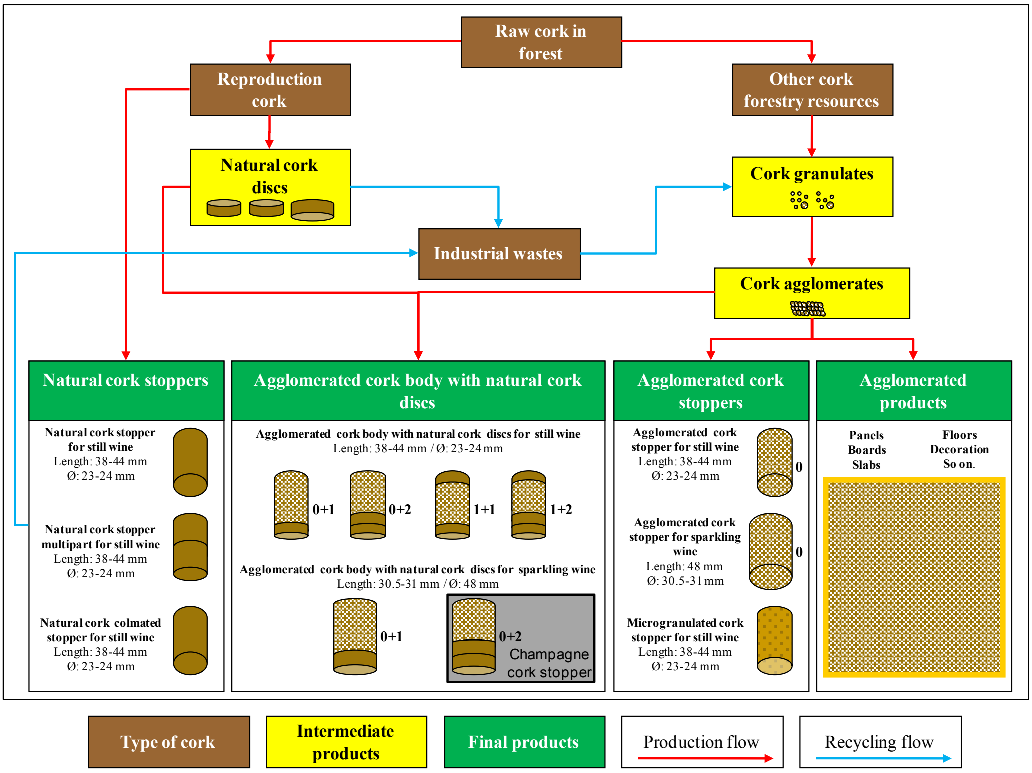



**Figure 6.1. Cork products: variety of cork stoppers depending on the type of cork used and the combination of intermediate products.**

Although a huge variety of stoppers exist, two specific stoppers were the most representative of the sector and the most produced: the natural cork stopper and a cork stopper made up of a cylindrical body of agglomerated cork topped by two superposed discs of natural cork. This last stopper is frequently known as the champagne cork stopper because it is specially conceived to seal champagne, cava, espumante and other types of sparkling wines and gaseous beverages. From now on the general term "champagne cork stopper" will refer to these stoppers. On bottling, a champagne cork stopper is introduced with discs as the bottom part so the natural cork will be the part in contact with the wine [74]. The agglomerated body must be produced by approved food contact glues to bind the cork granules together. Champagne cork stopper presents a larger diameter than natural cork stoppers for still wine, because they provide better mechanical resistance and make for greater compression against the neck of the bottle because it is essential in retaining the high internal pressures in bottles to preserve the quality of the content. These types of closures are chemically and mechanically very stable, and for this reason they are an economical solution for assuring a good seal for over 2 years. This product is the result of a highly industrialised industry.

Sparkling wine is a gasified wine with significant levels of carbon dioxide resulting from natural fermentation, possibly in a bottle, as with the *méthode champenoise* [195]. The classic example of a sparkling wine is Champagne, but many other types are produced in other countries and regions, such as Cava in

Northern Spain or Espumante in Portugal. The cork industry was developed in the Iberian Peninsula, because of the presence of wine sector in neighbouring areas [174] and because the cork raw-material is mainly harvested in this region [18]. The production of cork stoppers increased enormously in the 19th century and traditional manufacturers became considerable dimensions and turned into industrial poles [22]. In 2009, 1,300 million champagne cork stoppers were produced in Catalonia [20], this represented 60% of worldwide production [21]. The importance of the champagne cork stopper sector is related to the production of cava in Catalonia where 219 million cava bottles were produced in 2009 [196], but also because of the proximity of the producers of champagne and other sparkling wines in the rest of Spain as well as France, Portugal and Italy [21].

## 6.2. Goal and scope definition

The LCA methodology was selected to perform the environmental analysis of the system because it assesses all the global environmental impacts associated with a product, process or activity considering and evaluating the consumption of resources and emissions implicated. This study was based on the ISO 14040 regulations [109] that describe the procedures to realise the environmental assessment. Its fundamental steps are: (1) Goal and scope definition, (2) Life cycle inventory (LCI), (3) Life cycle impact assessment (LCIA) and (4) Life cycle interpretation [118, 120, 137, 141].

A gate-to-cradle study was carried out analysing the life cycle of champagne cork stopper production, covering the industrial system from the transport of the raw cork from the forests to the end of life of the product. All the flows required to produce the champagne cork stoppers were accounted and considered.

### 6.2.1. Objectives

In this study, the production of champagne cork stoppers was analysed from an environmental point of view, quantifying and assessing the environmental impact associated with their production, by means of the LCA methodology. Results would provide information relevant to the sector and identify the stages and operations that contributed most to the total environmental impacts. Moreover, from a perspective of cleaner production, the knowledge of which aspects of the production are most relevant will allow research to focus on future technological improvements to be made. The results will be an opportunity for producers to quantify and compare their own environmental impact, in order to analyse whether their production pollutes more or less than other companies in the sector, and to determine whether they can improve their production and their competitiveness. This research will mean a first approach to the best available techniques (BAT) reference document about champagne cork stopper production as there is no official reference document. Results, will allow for improvements in the production of other types of agglomerated cork stoppers in parallel. Until now, environmental research into champagne cork stopper production has not been carried out within previous research into natural cork stoppers [157].

### 6.2.2. Functional unit

The champagne cork stopper is a product used to seal bottles in order to conserve the content of a bottle saving all its characteristics. Each stopper has a diameter of 30.5 mm, a length of 48 mm and weighs 9 g. Besides, champagne cork stopper present a bevel at the top to indicate to bottling machines how to insert the stopper [25]. Other sizes and weights could exist, but they differ very little from the characteristics selected because the production is homogeneous. However, we have selected the most common characteristics in cork stopper production in order to obtain the most representative results. The Functional Unit (FU) established to refer all the flows involved in the production was one million standard champagne cork stoppers.

### 6.2.3. Description of the system under study

As described before, champagne cork stoppers are made of two parts: the granulated-agglomerated body and two discs made up by solid cork. Both parts can be considered as two separate intermediate products because their production could be easily differentiable. The production of champagne cork stoppers is similar in all companies but minor differences can exist, such as the transport of raw cork from different regions, or different percentages or types of glues incorporated in the stoppers etc. However, a general framework for the life cycle of champagne cork stoppers was considered in order to obtain results representative of the sector.

The forestry management subsystem will not be included because the research was focussed on the improvement of industries and not on forestry activities. Collection of forestry inventory data is complicated because forests and industries are managed by different companies and at the moment only industrial data are available. In principle, the impact of forest operations would be lower compared to industrial operations. Furthermore, another important fact that must be taken into account is that industrial system and forestry system are very different and must be addressed and researched individually and in depth.

In the following sections, each subsystem of the industrial champagne cork stoppers production will be described briefly (Figure 6.2). The industrial natural cork stopper system and the industrial champagne cork system are interconnected because some parts of raw cork material not unfit to produce natural cork products are derived to the champagne cork stopper industry. However, as natural cork stoppers were studied in previously research [157], we shall focus this research on the champagne cork stopper system.

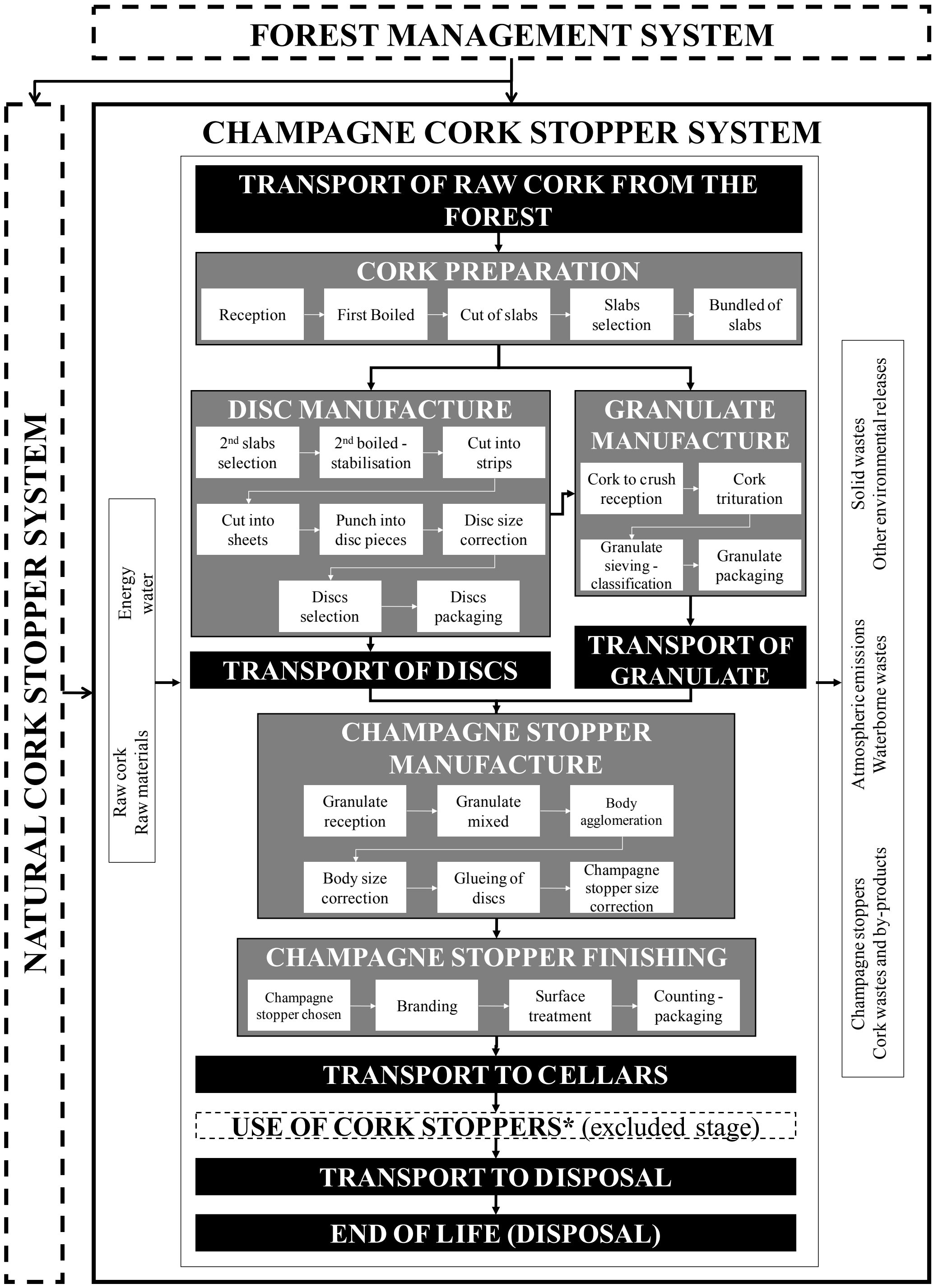



**Figure 6.2. General system framework of the life cycle of the industrial production of champagne cork stoppers: stages and production processes considered.**

## *Cork slab preparation*

Preparation is the first stage that must be carried out when producing any alimentary product made of cork because it guarantees the quality, health and safety of the raw material [184]. The preparation stage starts with the reception of the raw cork slabs from the forest after they have been sold by the owner and transported to the industries. Subsequently, some pieces of raw cork are eliminated because of unpleasant morphological defects such as cork showing yellowish stains on its back, green cork and clayed cork. Later, the slabs are boiled in a tank of hot water (100ºC) generally by immersion for 1 hour in order to remove organic solids, microorganisms and to humidify the cork [197]. Consequently, the cork is stabilised to avoid microbial growth activity. Later, the cutting of slabs take place and those slabs too big are cut in order to homogenise the raw material. Next, the slab selection operation is carried out and slabs are selected manually into three groups according to their use. Basically, those slabs with a thickness above 27 mm are sent to the natural cork stopper industry, slabs with a thickness below 27 mm are sent to the natural cork disc industry [64], and finally those slabs with morphological defects, virgin cork[10], second cork[11] small parts or fragments of cork and so on, are sent to the cork granulate industry. The bundling of slabs operation is the final operation to occur, and happens when the processes have been separated off to different production plants. In some cases cork slab preparation is carried out by a specific company often considered as an auxiliary industry which is usually located near the forest.

### *Disc manufacture*

After the preparation stage, the disc and granulate manufacturing stages take place in parallel. Two discs of natural cork are bonded to the end of the champagne cork stopper. These discs will be in contact with the content of the bottle and for this reason quality control of the agglomerated cork stopper includes the measurement of density and resistance parameters, i.e. torsion and tension, but the most important criteria in establishing the quality classification of these stoppers is ensured by estimation of the visible surface of the bottom disc of natural cork [74]. Disc manufacture consists basically in transforming prepared cork slabs into thin cylindrical pieces of 6 mm thickness and with a diameter of 34.5 mm. However, after joint body cork and disc agglomeration and after the stopper size correction operation, the diameter of the champagne cork stopper and subsequently the natural cork discs will be reduced to 30.5 mm.

Reception of the cork slabs is the first operation of this stage. After a second boiling operation is performed, consisting of an immersion of the cork slabs in clean boiling water for at least 30 minutes at a temperature close to 100ºC in order to increase cork flexibility and make it smooth. Consequently, cork slabs are stabilised and then cut into strips and then into sheets. After obtaining two or three sheets from every slab, every sheet is punched into discs. Finally discs are size rectified to obtain the desired dimensions and later selected by image analysis. Finally and only, in some cases were the production is done in different industrial plants, the discs are packaged and transported to the next stage.

During the disc manufacture stage some cork wastes are generated; (a) the back sheet and the belly sheet, (b) the remaining cork sheet after the punching of discs, (c) the discarded discs from the selection operation and (d) dust from size

[10] Virgin cork: first extraction of cork from young trees which presents deep fractures.

[11] Second cork: cork extraction for the second time which presents deep fractures.

correction. Most part of these wastes are send to manufacture granulates, but in some cases dusts were used in burning machines as a fuel substituting other non-renewable energy sources.

### *Granulate manufacture*

The cork to manufacture granulates is derived mainly from cork wastes generated during the production of natural cork products, as well as from forestry activities. Cork wastes from forests include all those fractions of raw cork material not suitable for single-piece natural cork products: cork slabs rejected because of excessive defects, cork fragments, virgin cork, second cork and so on. Two different types of cork granulate exist, white cork granulate and black cork granulate. Only the first granulate can be used to generate champagne cork stoppers because during their production a cleaning operation have been done to assure its healthy conditions for alimentary uses.

The granulate manufacture stage starts receiving raw cork materials, and then they are triturated or milled. Later, granulate screening or classification into different sized particles using density tables takes place, and consequently different granulate classes are obtained with dimensions generally between 0.25 mm and 8 mm. The resulting particles over 8 mm are reprocessed to obtain small sizes, while particles below 0.25 mm are considered cork dust. Finally, granulate of different classes is packaged in and moved on to the next stage. Different combinations of granulates could be made depending on the type of agglomerated product to be manufactured and also depending on the quality desired.

### *Champagne cork stopper manufacture*

In this paper we shall refer to the term *manufacture of champagne cork stoppers* for this stage, in order to avoid confusion with the term champagne cork stopper *production* that corresponded to the whole life cycle of the product. The body of the champagne cork stoppers is composed by a mix of small particles of triturated cork and adhesives as a binding agent. The granulometry of the particles varies from 0.25 mm to 8 mm, depending on customer need. Traditionally, the adhesive has been casein. Nevertheless, the present trend is to use polyurethane [184, 198]. These adhesives give homogeneity and porosity, and the percentage of adhesives varies from 10 to 15% in the final product [25].

Champagne cork stopper manufacture is a particular stage which starts by receiving and storing the cork granulates and glues. Later, they are mixed in moulding machines and subsequently, agglomerate bodies are generated. After some time of cooling and stabilisation, the body is 'beheaded' or size corrected in order to obtain the required size and form of the agglomerated body. Finally, the two discs are glued with polyurethane or casein to the bottom of the agglomerated body and the stopper is size corrected to obtain a homogeneous morphology of product with the required dimensions: a diameter of 30.5 mm, and a length of 48 mm.

### *Champagne cork stopper finishing*

Finishing is the last stage before distribution. It is performed to prepare the stopper for sale and consists of a stopper chosen to guarantee the quality of the product, a branding in fire, a surface treatment and a packaging operation. The surface treatment has the purpose of coating the stopper with a lubricant film, paraffin or silicone, to reduce friction in order to facilitate the introduction and extraction of the stopper from the bottle. Finally, the product is counted and packaged. The packaging is usually a cardboard box with two plastic bags , each containing 1,000 stoppers.

### *Transport subsystems*

Different stages of transport take place during the production of champagne cork stoppers. This is because the production is often fragmentised in many parts and locations. For example there are companies specialising in the preparation stage and that then sell prepared slabs to other companies that only produce discs or granulates, or companies in the sector that buy manufactured champagne cork stoppers to just finish and commercialise them. At the moment, most industries are only responsible for one part of the production process and only in a very few cases does an industry control the complete procedure from the forest to the final products. Because of this fragmentation, there are some types of transport that are very common in the sector: a) transport of raw cork materials from the forest to the preparation industry, b) transport of prepared slabs to the disc manufacture centre, c) transport of cork wastes from the natural cork product industries to the granulate industry, d) transport of granulates and discs to the champagne cork stopper manufacture stage, and e) distribution of the final product. In our system, we have considered the transportation that is normally used, while transportation that is exceptional or specific to a certain company has not been considered

## 6.2.4. Boundaries of the system

The study considered the whole of the system presented in the last section and the entire process of champagne cork stopper production from the transport from the forest to the end product. All the flows involved in the production were taken into account such as raw materials, water, energy, waste, etc. The general framework of the study can be observed in Figure 6.2.

Due to the fact that the objective of the study was the evaluation of industrial champagne cork stopper production, certain aspects may be excluded from the system [109]. One aspect not being evaluated was the use of industrial buildings and machines because their impact was negligible due to their very long useful life and their high production throughout that time. Something similar occurred with other particular aspects such as administration, laboratory activities, business operations, or maintenance of equipment and buildings.

The usage stage of the cork stoppers was excluded from the production analysis because it was considered to be negligible. Besides, the transport of auxiliary materials such as polyurethane, paraffin, cardboard boxes, and so on, was not quantified because they were provided by local enterprises and their impact was negligible compared to the different transports of the cork itself. Composition of glues and adhesives was approximated because auxiliary companies did not facilitate their exact composition.

Wastewater was excluded from the research because a quality analysis of its composition was not available and therefore this flow must be researched further. At the moment, only some basic parameters are measured such as pH, COD, total nitrogen and suspended materials.

Emissions associated to cork dust were not taken into account because they were considered very low in comparison of burning diesel oil in combustion machines. Also, it was considered that biomass use for energy generation is considered "carbon neutral" over its life cycle because combustion of biomass releases the same amount of $CO_2$ as that captured by the plant during growth [189]. Therefore, it must be pointed out that this source of energy was renewable and avoids the environmental impact of using other non-renewable sources of energy. A sensitivity analysis about this will be performed.

### 6.2.5. Life cycle inventory (LCI)

The life cycle inventory was obtained from the analysis of five Catalan companies that have as their primary purpose the production of champagne cork stoppers. These companies had implemented the ISO 9001 standards, are members of the enterprises Catalan association AECORK, and had recorded data from production over recent years. Companies have profiles of small and medium enterprises. Small companies comprise between 20-40 workers, producing between 35 and 55 million champagne cork stoppers yearly and work in a single shift. While medium companies have between 80 and 120 workers, producing more than 300 million champagne cork stoppers, and work continuously during 24 hours a day. Besides, produce champagne cork stoppers some of the companies produce other types of cork stoppers. Besides, all the companies provide data about the complete life cycle of champagne cork stopper production.

The system was characterised from fieldwork and also following the International Code of Cork Stopper Manufacturing Practice [184]. A general framework of the champagne cork stopper production was characterised at the beginning of the study. Following, a specific and complete questionnaire was prepared to collect data associated to production. It included numerous tables, one for every individual operation covering data over the entire production, and it asked for materials, energy, machinery, transport, waste and so on, related directly and indirectly to production. Finally, individual data of all the companies was obtained. These completed questionnaires collected crude data about all the stages and operations of the production process and also included non-manufacturing processes.

After obtaining the crude data from the different companies, the information was adapted to the FU. Due to the fact that the FU considers one million champagne cork stoppers, as a final product, the calculations were performed backwards, going from the end of the production process back to the transport of the raw materials. Then, a table for each company's inputs and outputs was generated and the five tables resulting from each company were averaged to achieve the average life cycle inventory of the sector. Due to reasons of secrecy, data and specific explanations of the production system of one particular company could not be shown. In fact, this study's intention is to analyse the whole sector and not a particular company.

### 6.2.6. Quality data and software

Data of the study was obtained directly from the companies, and all the producers reported the same kind of data. Different meetings took place between companies, the Catalan Cork Institute, (the reference institution of cork research) and the authors, in which the methodology to complete the questionnaires was reached by consensus. Moreover, authors visited the companies after they had completed the questionnaires to ensure data quality. All data were revised, controlled and verified by the Catalan Cork Institute. Data were generated from the production records of each company considering a minimum period of a year of production activity under normal conditions. Information related to machinery was extracted from manuals.

Data supported by companies were later averaged to generate results applicable to the sector in order to avoid particular cases. General production processes associated to producing raw materials, energy, transport and waste management were obtained from Ecoinvent 1.2 database [141].

The software Gabi 4.3 [193] was used to evaluate the environmental impact assessment, and the CML 2001 was the selected method to classify and characterise the environmental impact. This method is very useful to obtain category indicators at mid-point level: a problem oriented approach [138]. The impact categories considered were: Abiotic Depletion Potential (ADP), Global Warming Potential (GWP 100 years), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Layer Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), Human Toxicity Potential (HTP), Terrestric Ecotoxicity Potential (TETP), Freshwater Aquatic Ecotoxicity Potential (FAETP), Marine Aquatic Ecotoxicity Potential (MAETP) and Radioactive Radiation (RAD).

### 6.2.7. Allocation procedure and considerations

One of the most discussed methodological issues in LCA is the allocation procedure, especially for open-loop recycling systems. Although a lot of literature about the attribution of environmental burdens to a product exists, allocation is an ambiguous and complex task [136, 199-201]. System expansion including all the products generated from cork would be the best approach but it was impossible to analyse all the existing products with the research that had been carried out at the moment. Specifically, the allocation procedure related to champagne cork stopper system was complex due to the fact that two different parts was assembled: discs and agglomerated body, and because wastes generated in discs and from other natural products are then recycled into the system. The allocation established for each part was:

a) Discs allocation: all the inputs and outputs associated to the production of discs were allocated to disc manufacture because it has the greatest part of the economic value of the stopper and because it is the part most important of the stopper as it will be in contact with the contents of the bottle.

b) Granulates allocation: cork granulates to manufacture the agglomerated body, was resulted from cork wastes unavoidably generated during the production of natural cork stoppers and natural cork discs. In fact, some part of the wastes comes from the same system, while another part originates in the external natural cork stopper system that was studied previously by our group [157]. In this research, it was observed that significant cork wastes were generated and later sent to become granulate. However, as the objective of this industrial sector was the production of natural cork stoppers, all the environmental impact was attributed to this product, while for unavoidable cork wastes non-environmental burdens was assigned. This means that according to the cut-off method [136], applied to simplify the complexity of the system, cork waste must enter to the champagne cork system without attributing any environmental burden from its generation because it was already attributed to the products from which it has resulted. Thus, double accounting is avoided. However the recycling of these wastes was considered in the study system: concretely the subsystem granulate manufacture consider all the process which transforms cork wastes into new raw material. Also the transport of these wastes from natural cork stoppers industry to champagne cork stoppers industries were accounted and allocated to champagne cork stoppers.

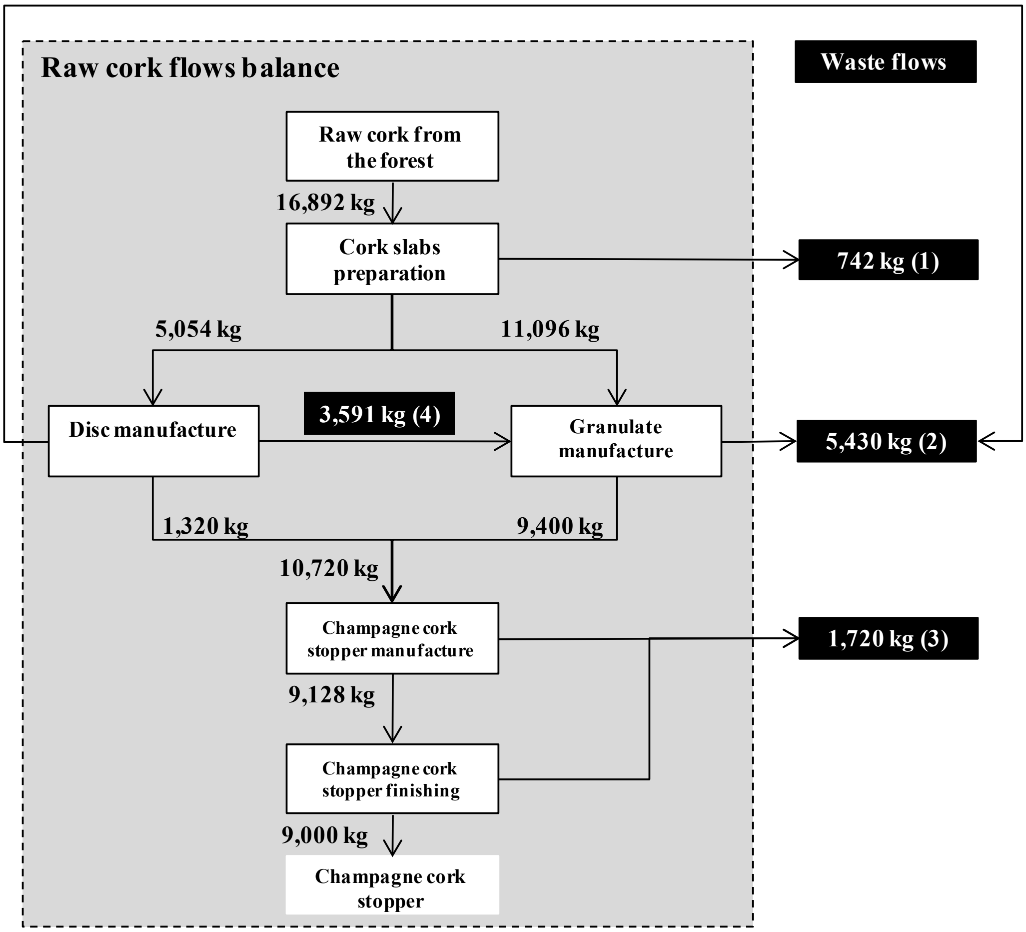
c) Cork dust flow: During the production of champagne cork stoppers, cork dust was used in some boiling operations as fuel. A non-environmental burden was allocated to those cork dusts because the objective of the production was to obtain cork products and cork dusts were collateral and unavoidable during the manufacture of different cork products. In the life cycle inventory (LCI) this flow was calculated, while in the life cycle impact assessment (LCIA), a non-environmental burden was assigned to it considering that it was "carbon neutral". However, a sensitivity analysis about the consideration of this flow was made at the end of this paper.

## 6.3. Results and discussion

The next section presents inventory and environmental assessment results. The contribution to the potential environmental impacts per stage and operations will be discussed in order to identify which are the weak points of the production. Finally, a sensitivity analysis was performed.

### 6.3.1. Inventory data of champagne cork stoppers production

As has been explained, inventory sector data was obtained from the average of the individual inventories. Raw cork flow balance was complex to understand because during the life cycle of the product, wastes of different characteristics were generated and later recycled in the same system but at another point of the production process. This was for example the case of most wastes generated during the production of natural cork discs recycled to generate granulate. Also, the complexity of the system was due to the fact that FU considered one million champagne cork stoppers obtained as a commercial product, and the calculations were performed in reverse order. Figure 6.3 shows an analysis of the raw cork flows balance to produce the FU. It can be observed that 16,892 kg of raw cork from the forest was required to produce the million champagne cork stoppers, weighting 9,000 kg in total. This means that 1.9 times the mass of cork was required to produce a unit. Although this seems to be an important loss of material, this rate is lower than that obtained for the production of natural cork stoppers, where 3.7 times the mass cork was required to produce a unit [157]. This fact was caused because natural cork stopper is made up by solid cork and due to the nature of the raw material, its imperfections and its morphological irregularities, a lot of material is needed.




(1) Cork slabs that could not be processed to alimentary uses.

(2) Cork dusts from sanding operations that can be used as fuel.

(3) Cork dusts with adhesives from sanding operations that can be used as fuel.

(4) Solid cork from natural cork discs recycled to manufacture white cork granulate.

**Figure 6.3. Raw cork flows balance to produce one million champagne cork stoppers weighing a total of 9,000 kg (FU).**

As detailed before, the champagne cork stopper is a product constituted by two intermediate products: natural cork discs and an agglomerated cork body. Each disc has a weight of 0.5 g in the final champagne cork stopper, but only once produced, it has a weight of 0.66 g - the loss of the 0.16 g is caused during the champagne cork stopper size correction operation. In fact, it was found that two million natural cork discs have an mean product weight of 1,320 kg. This means that considering that 5,054 kg of reproduction cork was needed to produce two million discs, the efficiency rate is similar for that of natural cork stoppers because 3.8 times the mass cork was required to produce a unit. However, most of the cork wastes generated during natural cork disc and stopper production will be recycled to manufacture cork granulates. It was estimated that 74% of the initial raw cork material will became a waste of the natural cork industry system after production. Also in figure 6.3, it can be stated that four types of waste were produced.

From the figure 6.3, it can be observed that high amounts of cork dust with or without adhesives was produced during the life cycle of champagne cork stoppers: in total 7,150 kg. However, at the moment only 21% of these wastes (1,528 kg) were used as renewable energy in the champagne cork stopper system substituting diesel oil. The remaining cork dust can be used as a filling agent for the poorest quality natural cork stoppers called often natural colmated cork stoppers, and also as an energy source in other external systems.

In Table 6.1, all the inputs and outputs associated to the production of the FU and a variability range indicator are reported. For example, an average of 19,775 litres of water was required for the sector to satisfy the FU, however the variability range in percentage for this flow was 51 to 145%; this means that one of the companies can produce the same by only needing 10,085 litres, while the least efficient in water consumption required 28,674 litres. The same fact could be observed for all the flows, but in some cases, the minimum was 0% because some of the companies did not use this resource.

There were not enough local cork resources to satisfy industrial production, and for this reason, raw cork material must be transported from other extractive areas such as Extremadura or Andalusia (Southern Spain) or Portugal. Moreover, it was observed that some companies bought granulate or discs manufactured in those regions and later they continue the production process. All the data of the suppliers were also demanded and applied to the study, and for this reason, different transport operations must be considered. Four important transport flows take place in the overall production system. However, here it must be pointed out that this transport corresponded to the sector average, and differences exist between companies. The first transport considered was those which the raw cork slabs from the forest was sent for preparation, the average flow of the sector resulting was 209 km. The transport of discs and granulates resulted as 872km and 667km, respectively, and the distribution was averaged from the sales of all the companies in 2009 around the world, for this reason two transport types were considered, one by lorry and one by freight ship, 827 km and 1,771 km were estimated, respectively. However, the variability range indicator for transport indicates that very important differences exist regarding the production within the different companies studied.

It was observed that each company has its own profile of flows required to satisfy the FU, and different combinations could exist: for example, it can be a company that was the most efficient in water consumption but the least efficient in raw cork consumption, or a company that was the most efficient in electricity use but that use large quantities of glue per stopper. Also, important differences exist between transport types. Thus, the optimal champagne cork stopper production would be that which combined the best practices of each company. Environmental diagnosis of the sector will allow integrated assessment of the complete life cycle and propose solutions for the most critical points of the production process.

**Table 6.1. Inventory data to produce one million champagne cork stoppers (FU).**

| Flows | Quantities average | Variab.range (%) (1) |
|---|---|---|
| ***Raw cork*** | | |
| Total raw cork required (kg) | 16,892.2 | 91-111 |
| Raw cork from forest to disks production (kg) | 5,054.2 | 95-108 |
| Cork wastes to granulate (kg) | 11,097.0 | 89-115 |
| ***Materials*** | | |
| Water (l) | 19,775.0 | 51-145 |
| Paraffin (Kg) | 22.7 | 0-500 |
| Silicone (kg) | 28.2 | 0-213 |
| Vaseline (kg) | 108.8 | 0-197 |
| Casein glue (Kg) | 111.5 | 0-156 |
| Polyurethane glue(kg) | 1,279.0 | 84-111 |
| ***Packaging*** | | |
| Sulphur dioxide ($SO_2$) (kg) | 0.9 | 0-271 |
| HDPE (kg) | 67.2 | 37-149 |
| Corrugated cardboard (kg) | 852.0 | 54-156 |
| ***Fuels used in the industrial production*** | | |
| Diesel oil (kg) | 1,156.8 | 11-434 |
| Cork dust (wastes) (kg) | 1,528.3 | 33-156 |
| ***Energy*** | | |
| Electricity (MJ) | 81,444.9 | 65-118 |
| ***Transport of raw cork*** | | |
| Raw cork from the forest (km) – by lorry | 209.3 | 24-143 |
| Discs (km) – by lorry | 872.0 | 2-138 |
| Granulate (km) – by lorry | 667.7 | 3-180 |
| ***Transport to cellars*** | | |
| To wineries (km) – by lorry | 827.2 | 64-132 |
| To wineries (km) - by freight ship | 1,771.4 | 0-216 |
| ***Transport of wastes considered*** | | |
| Champagne cork stopper disposal after consumption (km) | 50.0 | Assumed distance |
| **OUTPUTS** | | |
| **Flows** | **Quantities average** | **Variability range (%)** |
| ***Products*** | | |
| Champagne cork stoppers (kg) – UF | 9,000 | - |
| ***Cork wastes*** | | |
| Cork that couldn’t be processed to alimentary uses (kg) | 742.0 | 94-107 |
| Cork dust without adhesives (kg) | 5,430.0 | 90-112 |
| Cork dust with adhesives (kg) | 1,720.0 | 88-113 |

(1) This variability represented the differences of material required to produce the champagne cork stoppers FU depending on the company. The lowest percentage represented the company which used less quantity of inputs or transported over less distance.

## 6.3.2. Environmental impact assessment of champagne cork stoppers

The potential environmental impacts caused during the production of a million champagne cork stoppers are reported in Table 6.2. Most part of these impacts were caused due to the large quantities of electricity used during the production, 81,445 MJ. Results pointed out that 53,886 kg of $CO_2$ eq. were emitted during the industrial life cycle of a million champagne cork stoppers production; this corresponded to 53.9 g of $CO_2$ eq. per stopper.

**Table 6.2. Total environmental impact of champagne cork stopper production and range of variability between different producers.**

| Impact Category | Units | Total Impact | Variability range (%) (1) |
|---|---|---|---|
| ADP | kg Sb eq. | 406.29 | 88-110 |
| GWP | kg $CO_2$ eq. | 53,886.15 | 72-116 |
| AP | kg $SO_2$ eq. | 429.86 | 72-115 |
| EP | kg $PO_4^{3-}$ eq. | 35.86 | 88-112 |
| ODP | kg CFC11 eq. | 3.55E-03 | 79-127 |
| POCP | kg $C_2H_4$ eq. | 30.02 | 83-113 |
| HTP | kg 1.4 DB eq. | 11,142.96 | 77-114 |
| TETP | kg 1.4 DB eq. | 250.76 | 73-115 |
| FAETP | kg 1.4 DB eq. | 3,214.66 | 72-115 |
| MAETP | kg 1.4 DB eq. | 4.65E+07 | 68-117 |
| RAD | Kg Daly eq. | 6.78E-04 | 71-117 |

(1) This variability represented differences of the impact depending on the company. Percentages are relative to total impact results. The lowest percentage corresponded to the best environmentally producer, and the highest to the worst producer

Also, in Table 6.2 the variability range is presented. This indicator evaluated differences of environmental impact caused during the FU production depending on the company. Analysing this range for GWP, it can be observed that the most environmentally sensitive producer can generate the FU emitting 28% less $CO_2$ eq. than the sector average, while the least environmentally friendly production presented 16% more emissions than sector average. This was 38.8 g and 62.5, respectively. Results about variability range revealed that the company with the worst environmental production generated between 1.3 and 1.7 times more impact than the best producer, depending on the impact category considered, this indicated that the most polluting companies can improve their production environmentally with currently available technology that their competitors have already implemented.

## 6.3.3. Environmental impact assessment of the production of champagne cork stoppers by stages

Figure 6.4 presents the total environmental potential impacts associated to the production of champagne cork stoppers by stages.

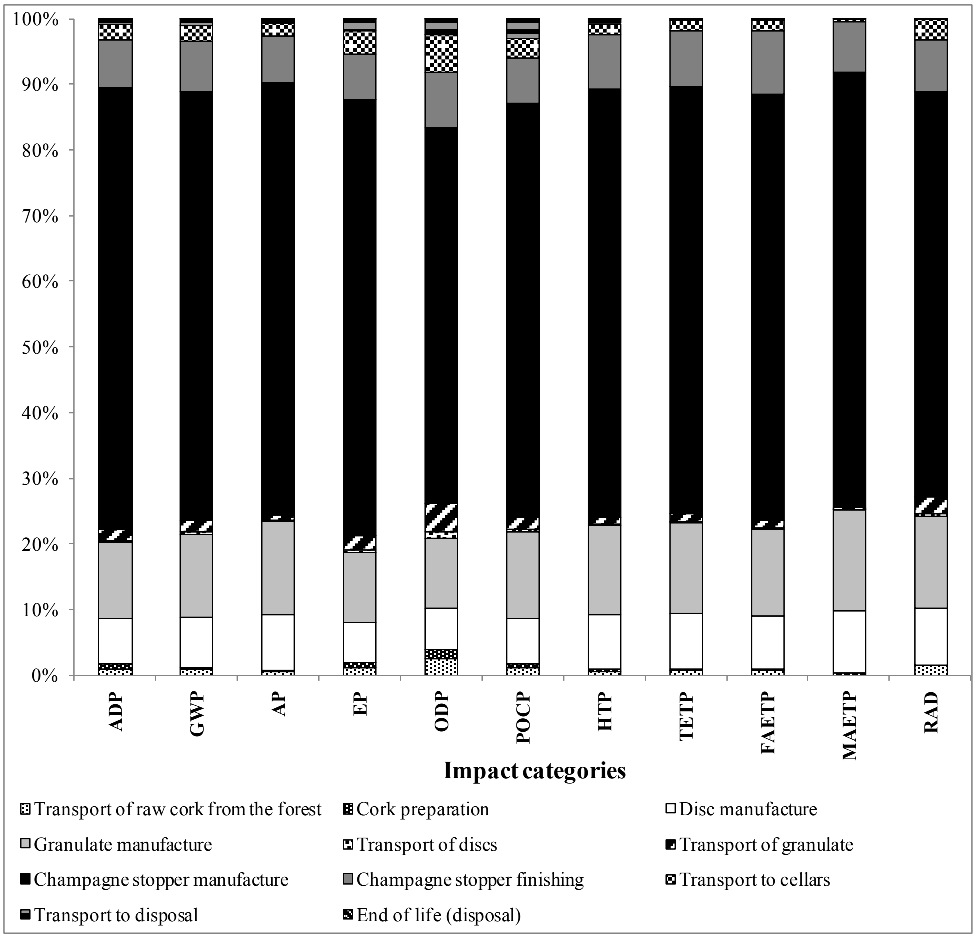



**Figure 6.4. Environmental impact assessment of champagne cork stoppers by production stages.**

Champagne cork stopper manufacturing was the stage which represented the greatest part of the environmental impacts caused during the whole life cycle, between 57-67% of the total impact, for all the categories studied: ADP, GWP, AP, EP, ODP, POCP, HTP, TETP, FAETP, MAETP and RAD. Those impacts were mainly caused to the high consumption of electricity because 66.6% of the total electricity of the system was consumed during this stage; more than 45,000 MJ.

Granulate manufacture was the stage that contributed second most for all the impact categories, with between 11 and 15% of the overall impacts, while champagne cork stopper finishing and discs manufacture stages represented between 6-10% of the impact. Otherwise, the remaining production stages: transport of the raw cork from the forest, cork preparation, transport of discs, transport of granulate, transport to cellar, transport to disposal and waste management contributed at most 6% in some of the categories, but in general did not contribute more than 2%.

For GWP, the champagne cork stopper manufacture stage was responsible of 65% of the $CO_2$ eq. emissions; while the cork granulate stage contributed 13% and disc manufacture and champagne cork stopper finishing stages were responsible of 8% emissions, each one. All the other stages in the life cycle of the product contributed together 6%, and anyone of them contributed <2%.

The following subsections will present the impact assessment of the four stages that contributed most. They will be presented in production order. These results will be fundamental to detect critical operations within the production process.

## *Disc manufacture stage: impact assessment*

Figure 6.5 shows the contribution of each operation within the disc manufacture stage. It can be observed that 2nd boiled - stabilisation and disc size correction were the operations that contributed most to disc manufacture stage for all the categories, 25% and 24%, respectively. Also the operation of punching into discs had an important contribution to the environmental impacts of this stage, between 21-22% in all the categories. While, all the other operations contributed less than 9%. Relative results of this stage by operation are very similar for all the impact categories because it is composed mainly by physical operations and for this reason, most part of the impact is caused because the use of electricity in cutting, punching and sanding machines.

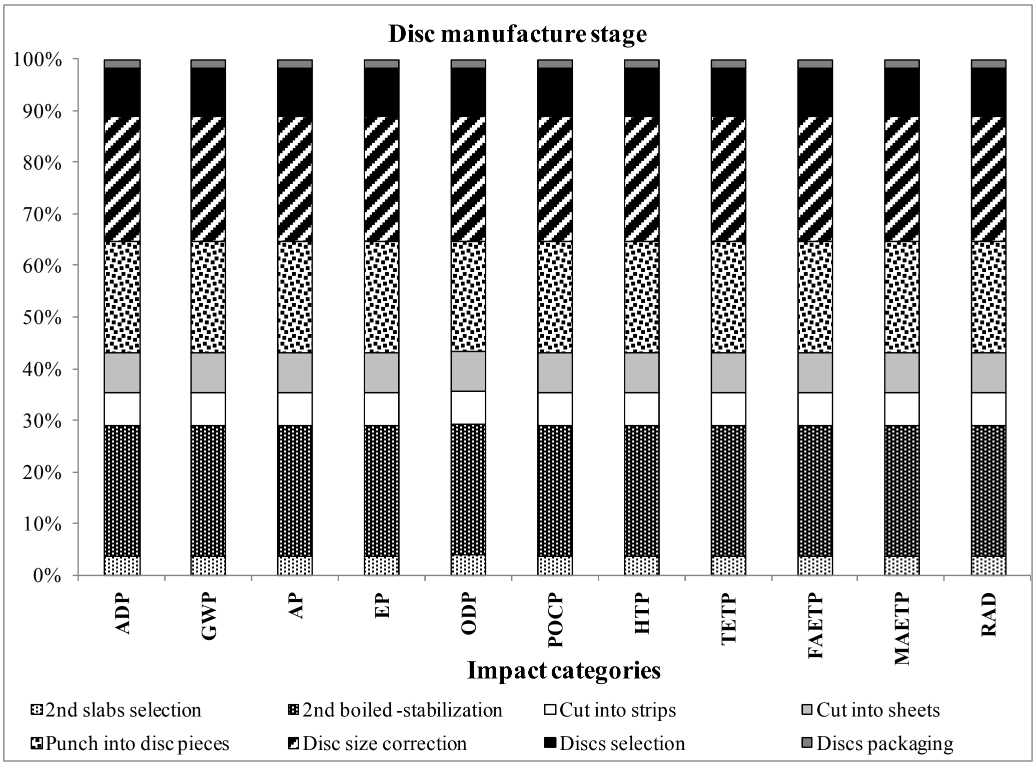



**Figure 6.5. Environmental impact of the disc manufacture stage by production operations.**

The production of discs could be an independent subsystem because it is an intermediate product that could be used to generate multiple types of cork stoppers as has been seen in the first section of this paper. In this case, it was considered as a part of champagne cork stopper because it was the final product analysis. Considering their main characteristics are a diameter of 30.5 mm, a length of 6 mm and a weight of 0.5 g, and only accounting those stages related to their production: transport of raw cork from forest, slabs preparation and natural cork discs manufacture; it has been obtained that 4.3 g of $CO_2$ eq. had been emitted per disc produced.

### *Granulate manufacture stage: impact assessment*

The environmental impacts generated during this stage were caused mainly by the electricity used. The greatest part of the environmental burdens related to the granulate stage was attributed to cork trituration, between 63-66% for all the categories analysed; and to granulate sieving – classification operation, between 31-34%. In this stage it is very clear that an improvement of these operations would mean a significant reduction of the environmental impact of this stage, while the improvement of the cork to crush reception and granulate packaging operations would mean very little environmental improvement. Figure 6.6 presents the contribution of each operation within the cork granulate stage.

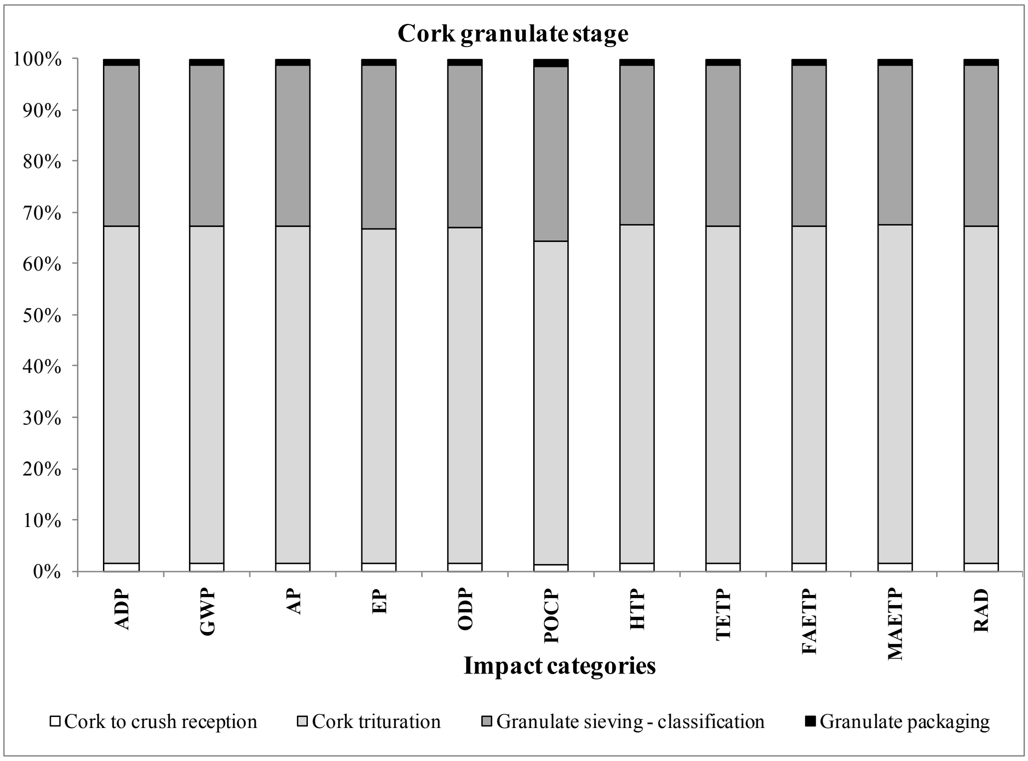



**Figure 6.6. Environmental impact of the cork granulate manufacture stage by production operations.**

## *Champagne cork stopper manufacture stage: impact assessment*

Body agglomeration was the operation that contributed most in the manufacturing stage in terms of ADP, GWP, AP, EP, ODP, POCP, HTP, TETP and FAETP, between 30-47% of those impacts, depending on the category (figure 6.7). Furthermore, MAETP and RAD have an important contribution, 25% and 27%, respectively. But for these two categories, gluing of discs was the operation that presented the greatest impact, corresponding to 28% and 29%, respectively. The gluing of discs was also the second most polluting operation, contributing between 21 and 27% for all the other categories. Champagne cork stopper size correction represented also an important part of the potential impacts, between 21-29%. The gluing of discs and champagne cork size correction operations' important contribution in this stage is associated with electricity consumption. For body agglomeration, the consumption of electricity is very important, but the introduction of polyurethanes was also in part responsible for these impact levels.

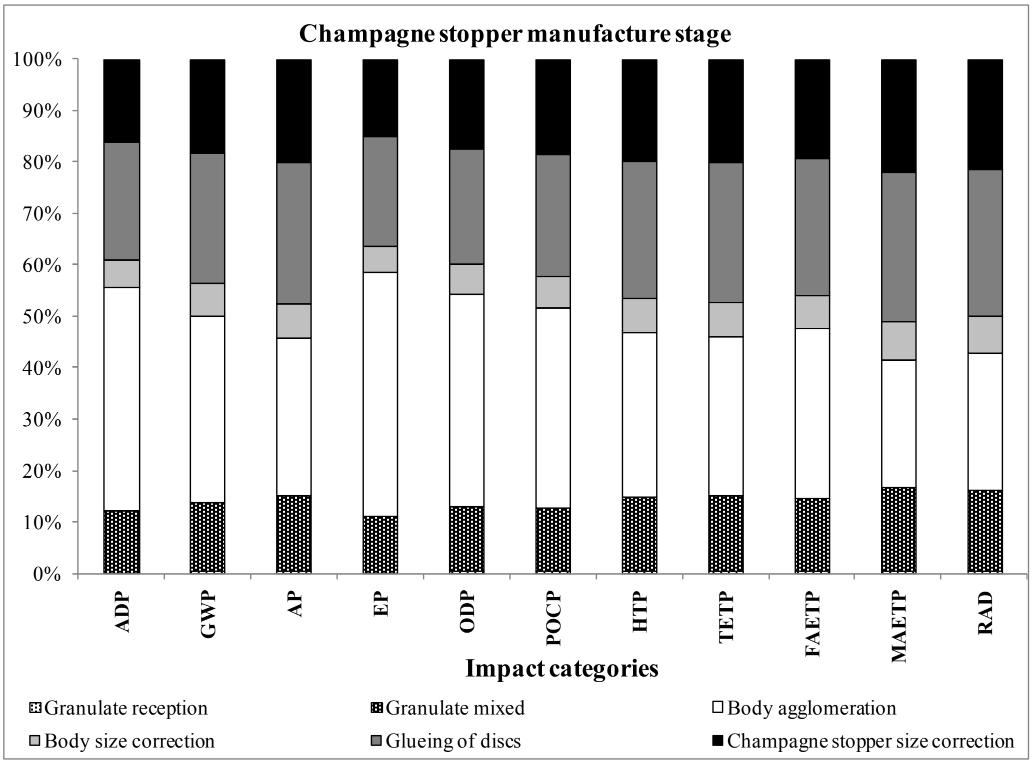



**Figure 6.7. Environmental impact of the champagne cork stopper manufacture stage by production operations.**

In Table 6.3, the environmental impact associated to champagne stopper manufacture and a variability range is shown. It can be observed that the average impact of the sector during this stage for GWP was 35,174.9 kg of $CO_2$ eq., while the most environmentally friendly producer generated only 49% of these impacts in this stage, the least environmentally sensitive producer generated 127%. From this category, it can be stated that the worst producer emitted 2.6 times more $CO_2$ eq., than the best one. For all the categories the same trend can be observed, but with different percentages. The least environmental producer, can generate between 1.4 and 3.4 times more impact during the manufacturing stage than the most environmental producer. It was found that these differences were most notable. Besides, as champagne cork stopper manufacture contributed between 57-67% of the total impact when producing the FU, it can be found that improvements in this stage could reduce notably the environmental impact associated to the overall production. Specifically, the total environmental impact of the champagne cork stopper industrial system considering the best manufacture stage can be reduced very notably, between 11-41%.

**Table 6.3. Environmental impact caused during champagne cork stopper manufacturing stage and range of variability between different producers.**

| Impact Category | Units | Average impact of the sector in manufacture stage | Variability range (%) (1) |
|---|---|---|---|
| ADP | kg Sb eq. | 273.0 | 83-118 |
| GWP | kg $CO_2$ eq. | 35,174.9 | 49-127 |
| AP | kg $SO_2$ eq. | 283.6 | 47-128 |
| EP | kg $PO_4^{3-}$ eq. | 23.8 | 83-118 |
| ODP | kg CFC11 eq. | 2.0E-03 | 75-137 |
| POCP | kg $C_2H_4$ eq. | 18.9 | 65-122 |
| HTP | kg 1.4 DB eq. | 7,278.7 | 55-126 |
| TETP | kg 1.4 DB eq. | 163.4 | 48-128 |
| FAETP | kg 1.4 DB eq. | 2,080.4 | 47-128 |
| MAETP | kg 1.4 DB eq. | 3.1E+07 | 39-131 |
| RAD | Kg Daly eq. | 4.2E-04 | 42-130 |

(1) This variability represented differences of the impact depending on the company. Percentages are relative to total impact results. The lowest percentage corresponded to the best environmentally producer, and the highest to the worst producer.

### *Champagne cork stopper finishing stage: impact assessment*

The analysis of operations carried out during the finishing of champagne cork stoppers indicated that three of the four operations contributed most to generate part of the potential impact caused during this stage: the branding contributed between 28-47%, depending on the category, the champagne cork stopper chosen contributed between 18-31% and the counting – packaging operation contributed between 11-40%. Also the contribution of surface treatment operation was important in terms of ODP, with 24% of the impact. Results of finishing stage can be observed in Figure 6.8.

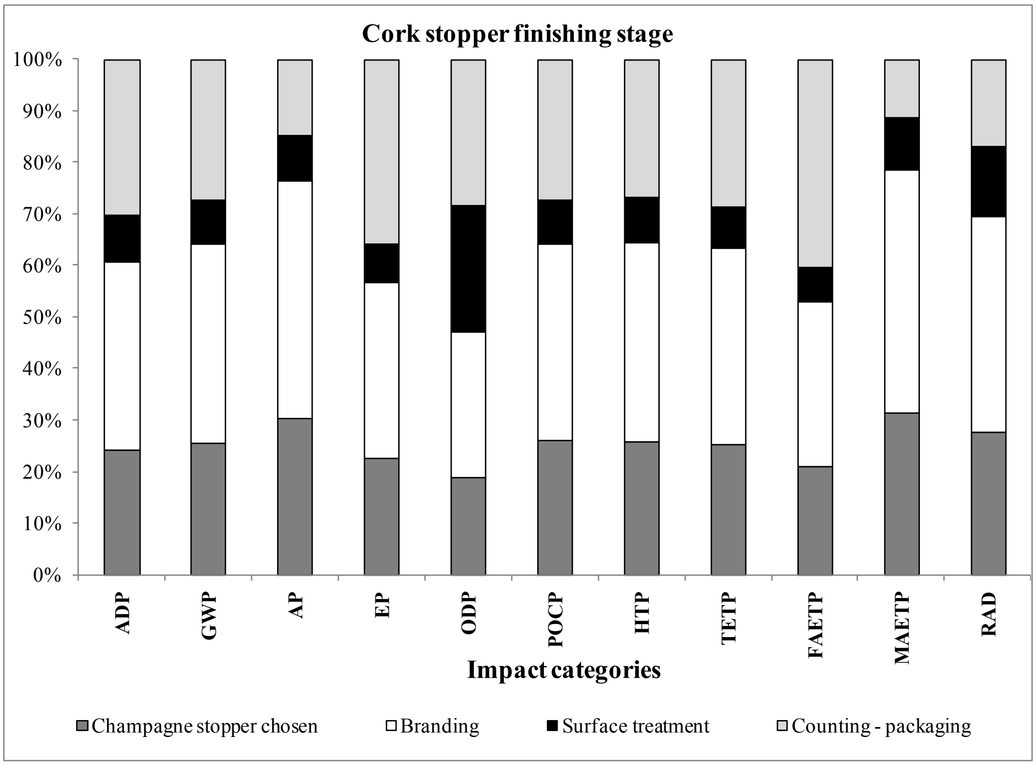



**Figure 6.8. Environmental impact of the champagne cork stopper finishing stage by production operations.**

## 6.3.4. Sensitivity analysis of cork dust utilisation as biomass

This subsection, analyses how the present substitution of diesel oil in some boiling operations by cork dusts contributed to reduce the environmental impact of the production, and also attempted to evaluate how the total potential substitution of diesel oil could reduce the present environmental impacts in future. It was considered that the highest heating values for cork dust was 24.7 MJ·kg$^{-1}$ [186], the highest heating value for diesel oil 44.9 MJ·kg$^{-1}$ [202], and an efficiency of the combustion of 80%. Three scenarios were considered:

- S1 – Reference scenario of the study which a non-environmental burden was allocated to cork dusts used as energy.
- S2 – Results considering that cork dust was not used in the system as energy and consequently more quantity of diesel oil was required (672 kg of diesel oil was considered equivalent that 1,528 kg of cork dust).
- S3 – This scenario attempted to analyse how environmental impacts associated with champagne cork stoppers production would decrease if all the diesel oil consumed now could be substituted by cork dust. It was considered that in total 2,629 kg of cork dust would be required.

Results indicated that the use of cork dust in the champagne cork stopper’s life cycle was a very positive aspect to minimising the environmental impact of the sector (Table 6.4). Scenario 2, that did not consider the use of cork dusts as energy is the less favourable in absolute terms. It can be stated that the environmental impact if cork dust is not applied to the system rises between 0.5 and 8.7%

depending on the category than the reference results obtained. Although the percentage of increase is not very high for all the categories, it was very interesting in terms of EP, ADP and especially for ODP.

**Table 6.4. Sensitivity analysis of the use of cork dusts as renewable fuel in the system.**

| Impact Category | Units | Total environmental impact | | | Impact difference (1) | |
|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S2 (%) | S3 (%) |
| ADP | kg Sb eq. | 406.3 | 422.4 | 378.5 | 4.0 | -6.8 |
| GWP | kg $CO_2$ eq. | 53,886.1 | 54,226.7 | 53,299.8 | 0.6 | -1.1 |
| AP | kg $SO_2$ eq. | 429.9 | 433.6 | 423.4 | 0.9 | -1.5 |
| EP | kg $PO_4^{3-}$ eq. | 35.9 | 37.1 | 33.7 | 3.5 | -6.0 |
| ODP | kg CFC11 eq. | 3.5E-03 | 3.9E-03 | 3.0E-03 | 8.7 | -15.0 |
| POCP | kg $C_2H_4$ eq. | 30.0 | 30.6 | 29.0 | 1.9 | -3.2 |
| HTP | kg 1.4 DB eq. | 11,143.0 | 11,323.0 | 10,833.0 | 1.6 | -2.8 |
| TETP | kg 1.4 DB eq. | 250.8 | 253.1 | 246.7 | 0.9 | -1.6 |
| FAETP | kg 1.4 DB eq. | 3,214.7 | 3,235.2 | 3,179.4 | 0.6 | -1.1 |
| MAETP | kg 1.4 DB eq. | 4.6E+07 | 4.7E+07 | 4.6E+07 | 0.5 | -0.8 |
| RAD | Kg Daly eq. | 6.8E-04 | 6.8E-04 | 6.7E-04 | 0.6 | -1.0 |

(1) Increase or reduction of the environmental impacts in relation to reference scenario (S1) in percentage.

Analysing the decrease of the environmental impact if no diesel oil was used in the champagne cork stopper production (S3); it can be observed that impacts generated during the life cycle could be reduced between 0.8 and 15%. This indicates that consumption of cork dust as renewable fuel is a good environmental technical improvement, although the reduction is not very notable in all the impact categories. Moreover, this potential is possible at the moment because inventory data revealed that only 1,528 kg of the 7,150 kg of cork dust generated during the production was used within the system. At the moment, some part of these cork dust was used as energy in other products or to seal natural cork stoppers with pores (lenticels) known as colmated natural cork stoppers. Some companies have recently started to implement the use of cork dust as biomass and it must be extended in the future, however, important economic investment must be made.

## 6.4. Conclusions

- In total, 16,892 kg of raw cork from the forest was needed to produce one million of champagne cork stoppers (9,000 kg of final product). This means that 1.88 times the mass of cork was required to produce a unit, and the requirement is lower than observed for natural cork stoppers that was 3.7 times [157]. The transformation of cork wastes to cork granulate is a way to take some advantage of these by-products of low economic value.
- Different input flows were required to satisfy the FU: 19.7 $m^3$ of water, 111.5 kg of casein glue, 1,279.0 kg of polyurethane glue, 1,156.8 kg of diesel oil, 1,528.3 kg of cork dust used as energy in boiling machines, so on. And, especially, large amounts of electricity were required 81,444.9 MJ.
- It was obtained that 53.9 g of $CO_2$ eq. was emitted when producing one champagne cork stopper that weighted 9 g. Besides, considering that 1,300 million champagne cork stoppers were produced in Catalonia in 2009, it was estimated that approximately 70,000 t of $CO_2$ eq. were emitted. In Table 6.2, all the environmental burdens associated with the production of one million champagne cork stoppers are reported.
- Champagne cork stopper manufacture contributed most to the total environmental impact of champagne cork stopper production, between 57-67% for all the impact categories analysed. It was also found that the greatest part of these impacts was caused by body agglomeration and disc gluing operations. Environmental improvements of the production must be focussed on these operations. It was stated that applying the best technology available at this stage the total environmental impact associated to the FU could be reduced notably, by between 11 and 41%, depending on the category.
- Some stages of the production represented less than 4% of the total environmental impact caused during production: transport of raw cork from the forest, cork preparation, transport of discs and transport of granulates, transport to disposal and end of life of the product stages. From a cleaner production perspective, the improvement of all the stages of the production are always interesting, but important changes in these stages will result in very little effective reduction of the overall environmental impacts associated to champagne cork stoppers production.
- It was stated that important differences existed among the production of champagne cork stoppers between companies. A stopper produced in the least favourable company from the environmental perspective, will present between 1.3 and 1.7 times the impact of the best company. This indicates that some companies of the sector can even optimise their systems with the technology or production practices that other competitors had implanted.
- The sensitivity analysis of diesel oil substitution by cork dust as a renewable source of energy showed that this contributes to reduce the environmental impact of the system. It was observed that a system that substitutes all the diesel oil per cork dust could reduce their impacts by between 6 and 15% for ADP, EP and ODP.

- Some improvements could be introduced in the production of champagne cork stoppers: (a) reduce the consumption of input flows; (b) use other renewable sources of energy such as solar energy instead of mains electricity (c) implement the best technology available for the champagne cork stopper manufacturing stage; (d) substitute diesel oil consumption in boilers by renewable sources of energy such as cork dust and other biomass.
- Results obtained in this paper would also serve to improve the production of other technical and agglomerated stoppers, because some of the stages are very similar.

# PART IV

## INTEGRATED EVALUATION OF THE CORK SECTOR AND IMPROVEMENTS FROM AN INDUSTRIAL ECOLOGY PERSPECTIVE

Chapter 7: Environmental analysis of the cork sector in Southern Europe (Catalonia – Spain) from an industrial ecology perspective

# Chapter 7

# ENVIRONMENTAL ANALYSIS OF THE CORK SECTOR IN SOUTHERN EUROPE (CATALONIA – SPAIN) FROM AN INDUSTRIAL ECOLOGY PERSPECTIVE

# 7. Environmental analysis of the cork sector in Southern Europe (Catalonia – Spain) from an industrial ecology perspective

This chapter is based on the following paper:

- **Rives, J., Fernandez-Rodriguez, I., Rieradevall, J., Gabarrell, X. Environmental analysis of the cork sector in Southern Europe (Catalonia – Spain) from an industrial ecology perspective). Submitted on July 2011 to Environmental Science & Technology.**


## Abstract

The importance of the cork sector lies in the use of cork to generate socio-economic benefits while contributing to the preservation of cork oak forests that are ecosystems typical of many Mediterranean areas. This sector comprises several activities around cork material and it is an example of symbiosis between subsystems. An important cork sector exists in South-western Europe, in Catalonia, a business which started to develop many centuries ago in this region. Although the cork sector is on a regional scale, cork products are consumed globally.

This study presents the environmental analysis of the cork sector by integrating and evaluating the production of the products that are most representative of cork: natural cork stoppers, champagne cork stoppers, white cork granulate and black cork granulate; in order to propose environmental strategies that could contribute to minimising the potential impacts of the cork sector from an industrial ecology perspective. Research was supported by data of more than 15 companies in Catalonia.

Results indicated that the cork sector contributed to fixing carbon dioxide and consequently can help to mitigate climate change, besides generating cork products. It was founded that 3.4 tonnes of $CO_2$ eq. were emitted to convert a tonne of raw cork from the forest into products, while 18 t of $CO_2$ are fixed per tonne because of cork oak forests; then the balance resulted that 14.6 t of $CO_2$ are fixed. It was also founded that 234 g of $CO_2$ are fixed when a natural cork stopper is generated, while 12 g are fixed by a champagne cork stopper; consequently, cork stoppers can contribute to reduce the carbon footprint of wines and other beverages. Finally, some strategies were analysed qualitatively from an industrial ecology perspective finding that they can help to improve the sector environmentally.



## Keywords

Carbon dioxide mitigation, cleaner production, cork products, life cycle assessment (LCA), Mediterranean, symbiosis.

# 7.1. Introduction

Cork oak (*Quercus suber L.*) forests are valuable ecosystems both ecologically and socio-economically [35]. They are naturally distributed around the western Mediterranean basin, and especially in the Iberian Peninsula where these forests cover more than 1.200.000 ha [18], specifically 55% of the cork oak surface area worldwide. The distribution of the tree is such because of specific ecological requirements: siliceous soils, mean annual temperature of around 15°C and 600-1,000 mm of annual rainfall [27]. The ecological importance of cork oak forests is associated to many environmental functions such as the combination of natural resources, water retention, soil conservation, biodiversity preservation, etc. [34, 171]; while their socio-economical role is based mainly on the extraction of cork and other forestry goods such as honey, pine cones, firewood, medicinal plants, etc. Actually, cork is the key element in these agro-forestry systems because it is generated in higher quantities than other goods, and consequently it generates higher economical benefits [39].

Cork is a natural and renewable raw material [65] obtained from the outer bark of cork oak [26]. The sustainable extraction of cork is ensured because the tree can be stripped without endangering the tree itself. After cork extraction the tree has the capacity of regrow a new outer cork bark. Cork is extracted every 9-14 years [67]. This period depends basically on the environmental conditions and cork growth rate, and consequently to the geographical location of the forest [41, 49, 160]. The cork oak tree can survive naturally for 250-350 years, but it is exploited until the tree is about 200 years old because of the loss of quantity and quality of cork after this period [17]. Cork can be extracted more than 12 times during technological life span of the tree.

The cork sector is an economically productive sector in some western Mediterranean areas. It started to develop in Catalonia; a north-eastern region between the Pyrenees and the Costa Brava; in the mid 18th century because there was raw material in this region [27], and because small scale craft workshops started to manufacture cork stoppers due to increasing demand for exportation to France, where there was an important production of wine and champagne [21]. This traditional sector is now evolving into a cluster in Catalonia: a geographical concentration of agents involved in the cork market because industries and forests are located within a diameter of under 200 km.. In the future, one of the strategies that the cluster wants to strengthen is sustainability. This challenge is one of the main justifications why the cork sector is currently performing studies and collecting data related to the environment.

The Catalan cork sector now comprises about 1,200 workers and 85 companies, with a turnover of about 230 million euro [20]. The sector is basically centred on two products that account for 98% of total sector revenues: the natural cork stopper and the champagne cork stopper [20]. This is mainly because other cork products have a very low value at the moment, and because cork has traditionally been used and is preferred to make tops for beverages bottles. In 2009, 10% of natural cork stoppers worldwide and 60% of the champagne cork stoppers were produced in Catalonia: 1,400 and 1,300 million, respectively [21].

Although, the cork products are produced on a regional scale, they are distributed and consumed around the world.

The cork sector is constituted mainly from two basic systems: the cork forest sector and the cork industry sector. Both parts were analysed environmentally by our group in previous research. The study was ordered on an industrial ecology perspective and on the availability of data. First, the three most representative industry products made of cork: natural cork stoppers [157], cork granulates [158] and champagne cork stoppers [159] were studied. And finally, cork extraction in Catalan cork oak forests [203] was evaluated. It would also be interesting to study the extraction of cork oak in other areas such as southern Spain or Portugal, which have a different model based on intensive exploitation. Usually, report data of industries is easier to obtain than data of forestry systems because of the degree of organisation and regulation of each subsystem. Industries have several sources of information: business statistics, machinery instructions, management system tools, auxiliary material labels, administrative documents, and so on; while forestry systems often only have the experience of their proprietors and basic information such as the annual consumption of diesel, the number of workers, or the yearly production of cork. The individual assessment by subsystem was a good approach to evaluate aspects that could not be found within the current integrated scope.

Industrial ecology (IE) is the perspective used in this dissertation. IE is a discipline, adapted from ecology, for the analysis and design of industrial systems as living systems that are interdependent with natural system [4]. The IE framework enables management of human activities on a sustainable basis by (a) minimising energy and material consumption, (b) ensuring an acceptable quality of life for people, (c) minimising the ecological impact of human activities to levels that natural systems can sustain, and (d) maintaining the economic viability of systems for industry, trade and commerce [7].

## 7.2. Methodology

This paper is based on IE concepts, especially industry symbiosis or metabolism that refer to the study of the physical materials and energy flows using a systematic approach. In fact, this paper apply the "*product-based systems approach*" which focuses on the impacts of a product, taking into consideration all the processes throughout its life cycle from raw material extraction to disposal [204]. The life cycle assessment (LCA) was found to be the most suitable tool to evaluate the cork sector from an industrial ecology perspective. Evaluation by means of LCA of other sectors had been previously carried out : construction [205, 206], energy and bio fuels [207-209], food [210], agriculture [211, 212], among others. The cork sector is evaluated environmentally and integrated for the first time. The ISO 14040 regulation [109] which serves to guide LCA studies was followed according to its basic steps: definition of goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation [138, 146].

### 7.2.1. Definition of goal and scope

The present paper is carried out to examine the cork sector as a whole system. The intended audience is all those involved in the development of the Catalan cork cluster: cork oak forestry owners, cork industries and institutions. The intention of this research is to assess the current cork sector from an environmental perspective but not a comparison between other sectors or products; however results will facilitate data for future comparisons.

In the current research, and according to the higher scope than previous studies, the cork sector will be analysed environmentally as a whole unit. Besides integration, the following objectives are also carried out:

1. To propose and evaluate qualitatively improvements to the current cork sector from an Industrial Ecology perspective.
2. To assess cork products by main stages, in order to detect whether the consideration of cradle-to-grave or cradle-to-gate scopes change the results obtained in previous research.
3. To carry out a global carbon dioxide balance of cork products and the cork sector considering fixation rates of cork oak forests.

Table 7.1 basically summarises the four cork products which have been used to analyse the cork sector from an integrated perspective. Furthermore, aspects related to these systems studied are explained: the function and the functional Unit (FU) of the product, system boundaries, allocation rules, and so on.

In each case study a particular FU was established for every product as can be observed in Table 7.1. For the integrated cork sector evaluation the FU established was an initial tonne of raw cork material converted into its most representative products according to distribution in mass, by the percentages found during the research. It was observed that 19% of the initial cork in the forest will became natural cork stoppers, 41% champagne cork stoppers, 7% white cork granulate, 7% black cork granulate and besides generating these four cork products, 26% of the initial raw material will become cork wastes. Most of these wastes is cork dust; sometimes used as fuel for certain operations of the sector substituting other non-renewable fuels. As can be seen in figure 7.1, the cork sector is a symbiotic system with several interconnections between cork flows.

**Table 7.1. Description of systems under study and their main characteristics.**

| | System 1 | System 2 | System 3 | System 4 |
|---|---|---|---|---|
| **Product** | **Natural cork stopper** | **White cork granulate** | **Black cork granulate** | **Champagne cork stop.** |
| **Reference study** | [157] | [158] | [158] | [159] |
| **Images** |  |  |  |  |
| **Function** | To seal still wine bottles in order to conserve the contents of the bottle, saving its physical, chemical and quality characteristics. | Raw material used to manufacture cork agglomerated products (technical stoppers) | Raw material used to manufacture cork agglomerated products (non-food products) | To seal champagne bottles, or other gaseous beverage bottles, in order to conserve the contents of the bottle, saving its physical, chemical and quality characteristics. |
| **Functional Unit (FU)** | One million standard natural cork stoppers: Diameter: 24±0.5 mm, Length: 44±49 mm Weight: 3.7±0.3 g) | One tonne of white cork granulate Size particles ranging from 0.25 to 8 mm | One tonne of black cork granulate Size particles ranging from 0.25 to 8 mm | One million champagne cork stoppers: Diameter: 30.5 mm Length: 48 mm Weight: 9 g. |
| **System description** | - All these products have been assessed in previous research without considering the forestry management stage required of local raw cork extraction.<br>- In this study the forest management stage is incorporated and following the system throughout the entire life-cycle of the products (cradle-to-grave, or cradle-to-gate). | | | |
| **System boundaries** | - Industrial buildings and machines were excluded because they are insignificant on the operation scale, as million of stoppers and/or tonnes of granulate are produced yearly.<br>- Administrative, laboratory, business and maintenance activities are not included in the systems because they are not attributed to production, and because they depend on companies' individual practices.<br>- Some inputs that represent a low percentage of the system (<2%) and which their composition was unknown were measured in the inventory but environmental burdens were not assigned to these flows.<br>- Wastewater treatment was not considered because of the lack of available data on its composition. The same happened in those products were cork dust was used as a renewable energy source. | | | |
| **Allocation rules** | - All the environmental burdens were assigned to natural cork stoppers, while burdens were not allocated to industrial cork wastes that are used in other production systems (cut-off method) | - The initial raw cork material for white cork granulate was 80% of industrial cork wastes without any environmental burdens allocated, and 20% of forest cork by-products. Consequently, to avoid double industrial cork wastes enter this system without impact allocation. | - The initial raw cork material for black cork granulate production originates in forests (cork by-products). Consequently, the environmental burdens associated to these materials was accounted for because they had not previously been accounted for and this material is always used to manufacture this product. | - As the champagne cork stopper is formed by two natural cork discs and an granulated-agglomerated body, different allocation rules were established for each part.<br>- All the environmental impacts associated with the production of natural cork discs were allocated to this intermediate product, while non burdens were allocated to industrial cork wastes used to manufacture the granulated-agglomerated body |
| **Number of companies analysed** | 4 (2 of them carry out the complete production, while 2 realise only one part of the production) | 3 (all of them also made other cork products) | 3 (all of them realised also other cork products) | 5 (2 of them realise all the production process as well as producing several other cork products) |

The distribution by products of the initial raw material is determined by the quality of the raw cork; mainly because of slab thickness and porosity [37] or defects [213]. The better the quality of the cork, the more natural cork stoppers that can be obtained and the amount of cork wastes are also minimised [69]. From this point of view then it is understandable that companies try to buy the best quality cork because it will be traduced to more efficiency in the production of natural cork stoppers, and consequently more profits can be obtained because this product is that which has higher added value and that is the main goal of the sector.

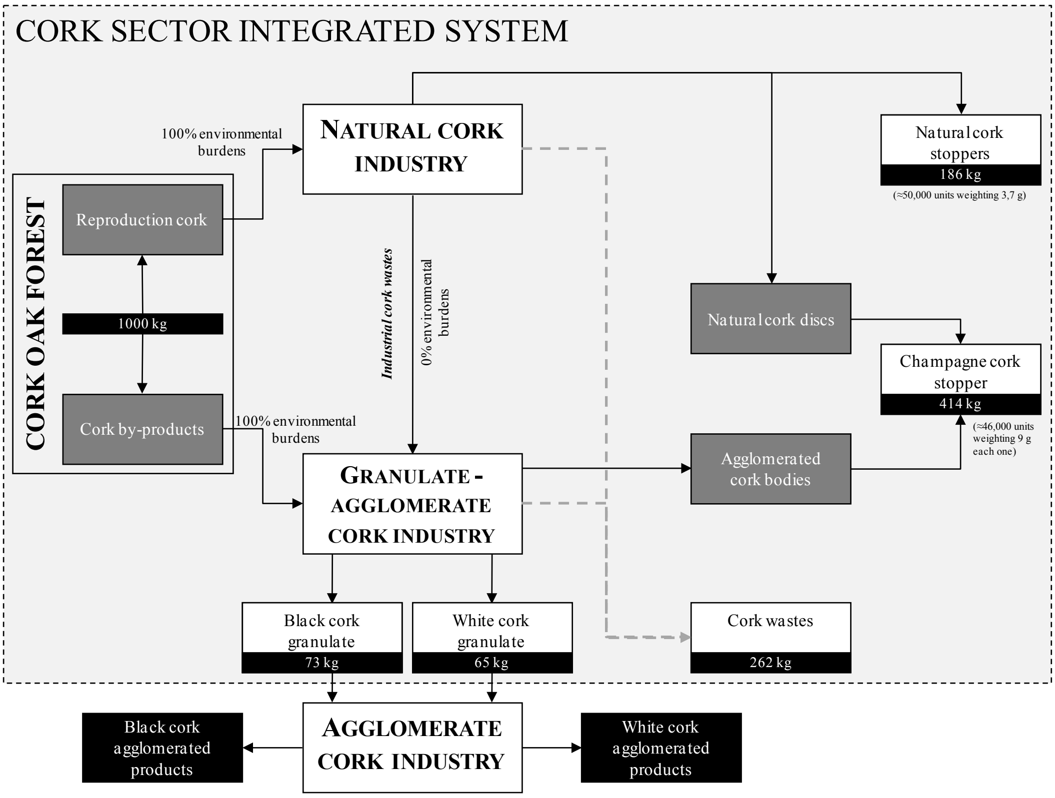



**Figure 7.1. Cork sector integrated system under study.**

Figure 7.1 presents schematically a diagram of the organisation of the cork sector according to its main products. The natural cork stopper and the champagne cork stopper are end products, while white and black cork granulated are intermediate products that must be later transformed into agglomerated products. For this reason, the natural cork stopper and the champagne cork stopper assessment was performed from cradle-to-grave; while white and black cork granulated was cradle-to-gate. On one hand, environmental assessment of natural cork stoppers and champagne cork stoppers was clearly justified because they represent 98% of the cork sector's total revenue, while other agglomerated cork products represent only 2% [20]. On the other hand, an environmental evaluation of white cork granulate and black cork granulate is also justified because these intermediate products are used in many applications and can be of interest for future LCA studies or databases.

White cork granulate is generated from natural cork industry wastes (80%) and forestry cork by-products (20%), while black cork granulate is generated only with forestry cork by-products. In fact both granulates are manufactured in similar production processes, but they are different because of the preparation stage required for white cork granulate because it is used for food packaging. As black cork granulate is intended to manufacture panels for construction, insulators, boards, and so on, such preparation is unnecessary [158].

It was stated during data collection that significant quantities of raw cork are imported from Portugal and southern Spain because there is insufficient cork in Catalan forests to satisfy the cork industry's demands. As there is no data available about the environmental impacts associated with cork extraction in these regions; it was assumed that there are similar impacts to those found in Catalan cork oaks. In future, cork extraction in these areas should be researched because the model of cork extraction is different and more intensive than in Catalonia.

Allocation rules should be established in order to avoid double accounting. The assignation of rules can be summarised as:

- All the materials that come directly from the forest had their respective environmental burdens assigned. This happens for reproduction cork and for cork-by-products.
- Non environmental burdens were assigned to industrial wastes resulting from other cork products; according to a cut-off method [136]. For natural cork stopper production, 100% of the impacts were allocated to stoppers and 0% to cork industry wastes. However, the mass required to produce a natural cork stopper unit was 3.7 times greater, and consequently the amount of cork industrial wastes resulting is higher than quantity of product obtained. This approach was considered because natural cork stoppers have a much higher economic value compared with industrial cork wastes.
- Although non environmental burdens were allocated to industrial cork wastes, transport of these materials, the recycling process and their subsequently impacts were considered. Intermediate products and transport between different companies were also considered.

At the end of this paper, a sensitivity analysis of how allocation rules affect results will be performed in order to analyse how different assumptions can modify the final results.

### 7.2.2. Life cycle inventory (LCI)

The life cycle inventory of each product was performed in previous research [157-159, 203]. LCI data was obtained for the period 2008-2011, and all the data was local and obtained directly from producers and cork oak forestry owners. Inventory data for each product was obtained after analysing between 3-5 experimental industrial installations or forestry exploitations depending on the system. The aim of the research was to find average results for the sector and not individual cases. In total, 15 companies or forestry owners were analysed in the study. Besides this, the Catalan Cork Institute; a reference research centre for cork; revised and verified all the data.

For each subsystem a specific inventory was developed in order to provide all the information required covering the whole life-cycle of the products. An example of these inventories and how sector averages was obtained can be observed in previous research [157]. During the collection data process several seminars, meetings and workshops took place in order to collect information on the system. Moreover, fieldwork was carried out in industrial installations and cork exploitation centres. Most of them were audited several times. In the present investigation, no other new inventory data was collected because the LCI used was calculated integrating data obtained up until now. We tried to avoid repeating information and results that are available in past publications.

### 7.2.3. Life cycle impact assessment (LCIA)

The impact assessment method selected was CML 2001 that is very helpful to obtain category indicators at a mid-point level [138]. The indicators or impact categories considered were: Abiotic Depletion (ADP), Global Warming Potential (GWP 100 years), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Layer Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), Human Toxicity Potential (HTP), Terrestric Ecotoxicity Potential (TETP), Freshwater Aquatic Ecotoxicity Potential (FAETP), and Marine Aquatic Ecotoxicity Potential (MAETP) [148].

The software tool Gabi 4.4 [145] was used. Mainly, local data obtained during the period 2008-2011 was used. Furthermore, the Ecoinvent v2.2 database [143] was used to complete the life cycle inventory for general processes [141, 147].

### 7.2.4. Interpretation

Interpretation will be performed in the discussion section from the results obtained from the LCI and LCIA and according to the definition of goal and scope. Finally, this step will help us arrive at conclusions and provide improvement recommendations for the cork sector.

## 7.3. Results

First, the environmental analysis of cork products is introduced: for natural cork stoppers and champagne cork stoppers corresponding to an entire life-cycle assessment of the product (cradle-to-grave); while for white and black granulate results were cradle-to-gate because they are intermediate products transformed later into other agglomerated products that were not assessed because numerous specific studies should be done for each one. In previous research [157-159], the forest management stage was excluded from industrial systems because there was no data available, and in this paper this stage is considered because it has now been studied [203].

Then, integrated cork sector evaluation is carried out according to a tonne of raw cork converted into cork products (FU). Later, a carbon dioxide balance between products is estimated, considering carbon dioxide fixed by cork oak forests. How the cork sector could help to mitigate climate change in a regional scale is also estimated. Finally, a sensitivity analysis about allocation rules is performed.

## 7.3.1. Impact assessment of the production of natural cork stoppers (cradle-to-grave)

Human activities are responsible for several environmental impacts, and the production of natural cork stoppers is no exception. The environmental impacts of the entire life cycle of the natural cork stopper are higher than the industrial production cycle alone. Specifically, the absolute value of the impacts increases between 11-33% depending on the category analysed as a consequence of integrating the forestry management stage in the results. Table 7.2 presents the environmental impacts caused by the natural cork stoppers' life-cycle. The FU for this subsector was 1 million natural cork stoppers, weighing a total of 3,700 kg.

**Table 7.2. Environmental impact assessment of natural cork stoppers considering only the industrial production system and the entire life-cycle.**

| Impact Category* | Units | Forest management | Forest management (%) | Industrial cycle | Industrial cycle (%) | Total |
|---|---|---|---|---|---|---|
| ADP | kg Sb eq. | 18.3 | 14 | 116.6 | 86 | 134.9 |
| GWP (1) | kg $CO_2$ eq. | 2,649.1 | 19 | 10,947.0 | 81 | 13,596.1 |
| AP | kg $SO_2$ eq. | 12.0 | 11 | 101.1 | 89 | 113.1 |
| EP | kg $PO_4^{3-}$ eq. | 2.3 | 14 | 14.0 | 86 | 16.3 |
| ODP | kg CFC11 eq. | 3.7E-04 | 17 | 1.8E-03 | 83 | 2.2E-03 |
| POCP | kg $C_2H_4$ eq. | 2.6 | 16 | 13.7 | 84 | 16.3 |
| HTP | kg 1.4 DB eq. | 695.1 | 23 | 2,309.1 | 77 | 3,004.3 |
| TETP | kg 1.4 DB eq. | 15.8 | 25 | 47.7 | 75 | 63.5 |
| FAETP | kg 1.4 DB eq. | 177.7 | 18 | 833.3 | 82 | 1.011.0 |
| MAETP | kg 1.4 DB eq. | 6.5E+05 | 10 | 6.0E+06 | 90 | 6.7E+06 |

* These values are calculated according the established FU: one million natural cork stoppers (3,700 kg)

(1) GWP indicator in this case only account for the emission of $CO_2$ eq. associated with the system, while the potential $CO_2$ fixed as a consequence of cork oak forests is not considered in these results.

In figure 7.2, it can be observed how environmental impacts of natural cork stoppers are distributed by stages when the entire life cycle is considered. It can be stated that cork stopper manufacture is the stage that contributed most in practically all the categories, between 24-58%. Only for EP and POCP, cork transport from the forest contributes more than the manufacturing stage; 35 and 36% respectively. Moreover, the forestry management stage represented an important part of the environmental impact; between 10-25% depending on the category analysed. It was the second most impacting stage in terms of HTP and TETP.

Distribution of impacts between stages are similar to that obtained in a previous study [157], however the percentages are lower than those found because the forestry management stage was not considered there. Then, from a cleaner production perspective, it is also recommended that the manufacturing stage improve according to the present results, particularly the cylindrical piece punching, the size correction and the second boil operations.

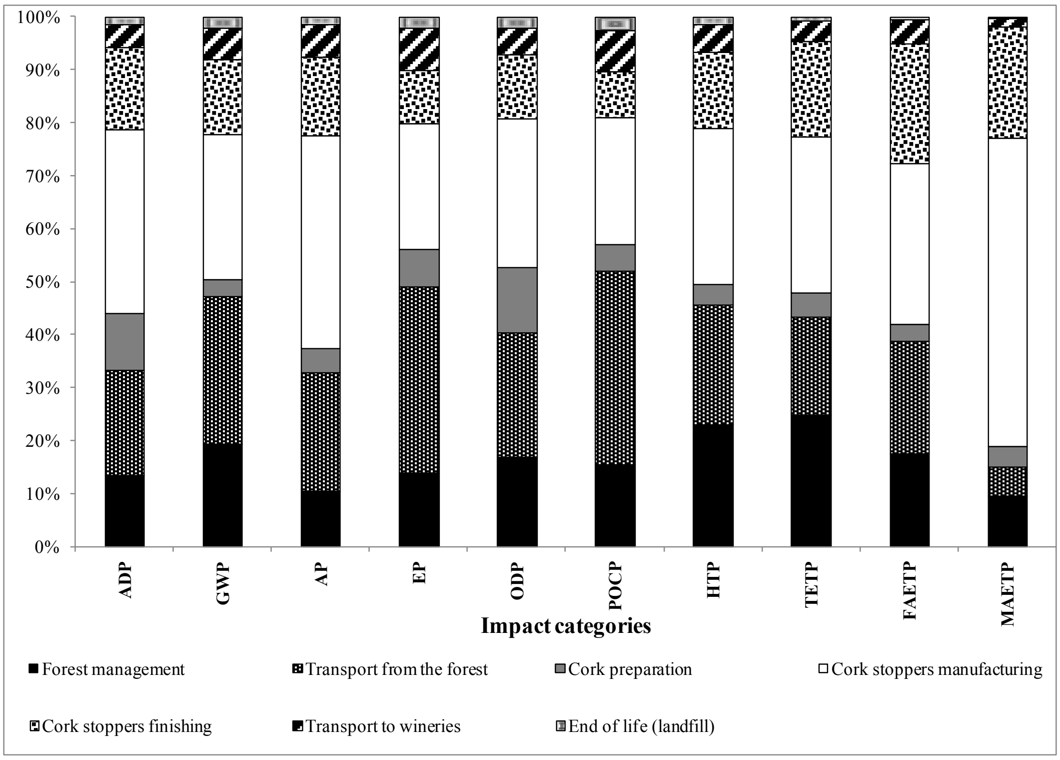



**Figure 7.2. Environmental impact assessment of natural cork stoppers in production stages considering the entire life-cycle of the product.**

## 7.3.2. Impact assessment of the production of cork granulate (cradle-to-gate)

Tables 3 and 4 presents the environmental analysis of white cork granulate and black cork granulate considering a cradle-to-gate system: from the initial raw material until the product is manufactured and available to go on to produce agglomerated cork products. Tables are calculated according to an FU of 1 tonne of cork product. Cork granulates are one clear example of the symbiosis within the cork sector, because cork raw material with low economical added-value and industrial cork wastes from natural cork industry are used to manufacture granulates that will later became agglomerated products. Then, it can be outlined that cork wastes for one subsector are often used as raw material for other subsectors.

As also happened for the natural cork sector, the introduction of the forestry management stage causes potential environmental impacts to rise in both cases.

However, in white cork granulate the increase is lower (between 2-19%) than for black cork granulate which is between 10-99%. This is a direct consequence of allocation rules, because the initial raw material that enters black cork granulate production comes from the forest and then, all the impacts are allocated to this intermediate product.

For white cork granulate, the forest management stage contributed between 2-16% in all categories, while the industrial cycle contributed between 84-98% (table 7.3). Moreover, the manufacturing stage contributed between 77-95% for all the categories, while preparation and transport from forest stages represented at most 4% of the impacts.

**Table 7.3. Environmental impact assessment of white cork granulate considering only the industrial production system and the cradle-to-gate life-cycle.**

| Impact Category* | Units | Forest management | Forest management (%) | Industrial cycle | Industrial cycle (%) | Total |
|---|---|---|---|---|---|---|
| ADP | kg Sb eq. | 0.4 | 8 | 5.0 | 92 | 5.5 |
| GWP (1) | kg $CO_2$ eq. | 62.0 | 7 | 772.1 | 93 | 834.1 |
| AP | kg $SO_2$ eq. | 0.3 | 4 | 6.4 | 96 | 6.7 |
| EP | kg $PO_4^{3-}$ eq. | 0.1 | 11 | 0.4 | 89 | 0.5 |
| ODP | kg CFC11 eq. | 8.6E-06 | 16 | 4.4E-05 | 84 | 5.3E-05 |
| POCP | kg $C_2H_4$ eq. | 0.1 | 10 | 0.5 | 90 | 0.6 |
| HTP | kg 1.4 DB eq. | 16.3 | 9 | 159.9 | 91 | 176.1 |
| TETP | kg 1.4 DB eq. | 0.4 | 9 | 3.7 | 91 | 4.0 |
| FAETP | kg 1.4 DB eq. | 4.2 | 8 | 45.2 | 92 | 49.4 |
| MAETP | kg 1.4 DB eq. | 1.5E+04 | 2 | 7.3E+05 | 98 | 7.5E+05 |

* These values are calculated according the established FU: a tonne of white cork granulate

(1) GWP indicator in this case only accounts for the emission of $CO_2$ eq. associated with the system, while the potential $CO_2$ fixed as a consequence of cork oak forests is not considered in these results.

For black cork granulate, the forest management stage contributed between 9-50% in all the categories, while the industrial cycle contributed between 50-91% (table 7.4). Moreover, the manufacturing stage contributed between 77-95% for all categories, while preparation and transport from forest stages represented at most 4% of the impacts. Manufacturing is still the most impacting stage of all the categories, (between 46 - 90%) for practically all the potential environmental impacts. In fact, only for ODP forest management stage has a similar contribution, 50% of the manufacturing stage. The transport from the forest represents at most 2% of the impacts because it is on a local scale.

**Table 7.4. Environmental impact assessment of black cork granulate considering only the industrial production system and the cradle-to-gate life-cycle.**

| Impact Category* | Units | Forest management | Forest management (%) | Industrial cycle | Industrial cycle (%) | Total |
|---|---|---|---|---|---|---|
| ADP | kg Sb eq. | 2.1 | 30 | 5.0 | 70 | 7.1 |
| GWP (1) | kg $CO_2$ eq. | 309.9 | 29 | 770.3 | 71 | 1,080.3 |
| AP | kg $SO_2$ eq. | 1.4 | 18 | 6.4 | 82 | 7.8 |
| EP | kg $PO_4^{3-}$ eq. | 0.3 | 38 | 0.4 | 62 | 0.7 |
| ODP | kg CFC11 eq. | 4.3E-05 | 50 | 4.3E-05 | 50 | 8.6E-05 |
| POCP | kg $C_2H_4$ eq. | 0.3 | 35 | 0.5 | 65 | 0.8 |
| HTP | kg 1.4 DB eq. | 81.3 | 34 | 159.1 | 66 | 240.4 |
| TETP | kg 1.4 DB eq. | 1.8 | 34 | 3.7 | 66 | 5.5 |
| FAETP | kg 1.4 DB eq. | 20.8 | 32 | 45.1 | 68 | 65.9 |
| MAETP | kg 1.4 DB eq. | 7.6E+04 | 9 | 7.3E+05 | 91 | 8.1E+05 |

* These values are calculated according the established FU: a tonne of black cork granulate

(1) GWP indicator in this case only accounts for the emission of $CO_2$ eq. associated with the system, while the potential $CO_2$ fixed as a consequence of cork oak forests is not considered in these results.

Comparing results by stages for white and black cork granulate, it can be stated that the forestry management stage has greater importance in the second case. However, this is caused because of allocation rules and the cut-off method established. As was described in methodology, most of the initial raw cork material used to produce white cork granulate (80%) entered the system without any environmental burden. For black cork granulate, forestry activities increased the environmental impacts notably because all the impacts of cork by-products were allocated to this intermediate product as they were not accounted to other products.

Nevertheless, cork granulates continue to represent a renewable raw material with far fewer impacts than other non-renewable raw materials. In fact, cork granulates are a solution to optimise the cork wastes generated by the natural cork industry and to give a function to these cork by-products from the forest with low economical value. Cork granulates are manufactured from local resources because to import material from distant regions is not economically viable due to the low added value of the resulting products means that costs exceed benefits.

### 7.3.3. Impact assessment of the production of the champagne cork stopper (cradle-to-grave)

Environmental impacts caused by the cradle-to-grave champagne cork stopper system can be observed in Table 7.5 according to a specific FU of a million champagne cork stoppers weighing a total 9,000 kg. In this case, the difference between the results of the complete or the industrial system differ by at most 5%. This very low increase can be explained by two facts:

(a) champagne cork stoppers are a product constituted of two parts: two natural cork discs of 0.5 g each, and an agglomerated cork body composed of white cork granulate which weighs about 8 g. According to the cut-off method 80% of the mass contained in the cork body is free of environmental charges because it is constituted by white cork granulate.

(b) the greater the total environmental impact caused because of industry cycle of a product, the less significant the contribution of the forestry management stage. As the total environmental impact of the champagne cork stopper's industrial cycle is higher than the natural cork stopper an increase of the impact is less significant in percentage terms.

**Table 7.5. Environmental impact assessment of champagne cork stoppers considering only the industrial production system and the entire life-cycle.**

| Impact Category* | Units | Forest management | Forest management (%) | Industrial cycle | Industrial cycle (%) | Total |
|---|---|---|---|---|---|---|
| ADP | kg Sb eq. | 9.6 | 2 | 406.3 | 98 | 415.9 |
| GWP (1) | kg $CO_2$ eq. | 1,394.0 | 3 | 53,886.1 | 97 | 55,280.1 |
| AP | kg $SO_2$ eq. | 6.3 | 1 | 429.9 | 99 | 436.2 |
| EP | kg $PO_4^{3-}$ eq. | 1.2 | 3 | 35.9 | 97 | 37.1 |
| ODP | kg CFC11 eq. | 1.9E-04 | 5 | 3.6E-03 | 95 | 3.7E-03 |
| POCP | kg $C_2H_4$ eq. | 1.3 | 4 | 30.0 | 96 | 31.4 |
| HTP | kg 1.4 DB eq. | 365.8 | 3 | 11,143.0 | 97 | 11,508.7 |
| TETP | kg 1.4 DB eq. | 8.3 | 3 | 250.8 | 97 | 259.1 |
| FAETP | kg 1.4 DB eq. | 93.5 | 3 | 3,214.7 | 97 | 3,308.2 |
| MAETP | kg 1.4 DB eq. | 3.4E+05 | 1 | 4.7E+07 | 99 | 4.7E+07 |

* These values are calculated according the established FU: 1 million champagne cork stoppers (9,000 kg)

(1) GWP indicator in this case only accounts for the emission of $CO_2$ eq. associated with the system, while the potential $CO_2$ fixed as a consequence of cork oak forests is not considered in these results.

As can be observed in figure 7.3, the forestry management stage contributed less than 5% in all the impact categories. Transport of raw cork from the forest had a lower contribution in the life-cycle system of the champagne cork stopper than for the natural cork stopper. This is basically due to two different facts. The first reason is that the initial raw cork material is transported to manufacture natural cork stoppers and not industrial cork wastes, therefore the impacts of this stage is allocated to this product and not to industrial cork wastes that later become the agglomerated cork body of the champagne cork stopper. The second reason is that during champagne cork stopper production two intermediate transports take place: transport of discs and transport of granulates. These transports are a consequence of a fragmented or specialised production. It is quite frequent that champagne cork industries are divided into different plants located in different geographical areas which produce a specific product, or even industries that realise only one part of the production process: e.g. the production of cork discs, the production of cork granulate, the assembly of cork discs with cork agglomerated body or the finishing of the champagne cork stoppers. However, considering all the raw cork material or intermediate products required to produce champagne cork stoppers, they represent between 1-7% of the impacts depending on the category analysed.

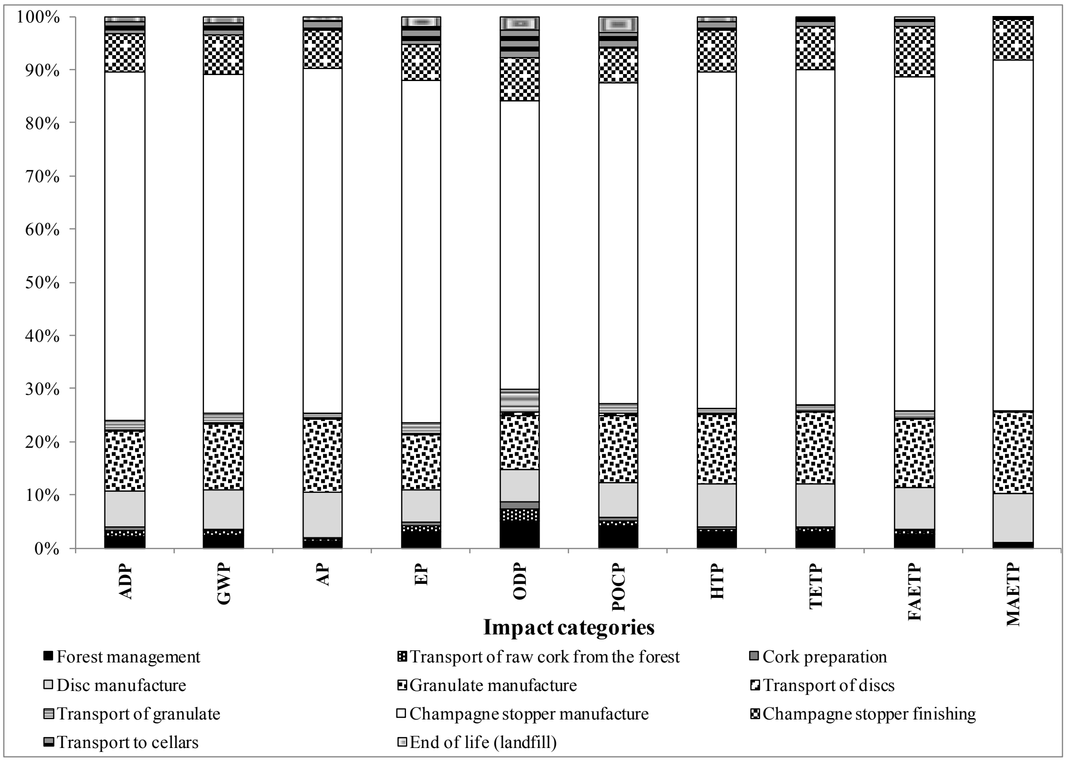



**Figure 7.3. Environmental impact assessment of champagne cork stopper by production stages considering a cradle-to-gate system.**

The cleaner production strategies for champagne cork stopper production proposed in previous research [159] are also recommended, because they consider the forestry stage's effect on raising the impacts to be very low. Therefore, improvement of the operations involved in the champagne cork manufacture stage, especially body agglomeration and disc gluing operations, are recommended to reduce the global environmental impact of the product.

### 7.3.4. Integrated impact assessment of an initial tonne of raw cork material converted into their most typical products (integrated FU)

Table 7.6 presents the environmental burdens assigned to the integrated FU[12]: a tonne of raw cork material converted into their most emblematic products. It was calculated according the environmental impact caused by each product, and considering the percentages of each one. It can be stated that 3,359.4 kg of $CO_2$ eq. were emitted to generate the FU. Most of this emission should be attributed to the champagne cork stopper subsystem (76%) and the natural cork stopper (20%).

**Table 7.6. Environmental impact assessment of an initial tonne of raw cork material converted into their most representative products.**

| Impact Category | Units | Natural cork stopper | White cork granulate | Black cork granulate | Champagne cork stopper | Cork wastes | Total (2) |
|---|---|---|---|---|---|---|---|
| Reference | Kg | 186 | 65 | 73 | 414 | 262 | 1,000 |
| ADP | kg Sb eq. | 6.8 | 0.4 | 0.5 | 19.1 | 0.0 | 26.8 |
| GWP (1) | kg $CO_2$ eq. | 683.5 | 54.2 | 78.9 | 2,542.9 | 0.0 | 3,359.4 |
| AP | kg $SO_2$ eq. | 5.7 | 0.4 | 0.6 | 20.1 | 0.0 | 26.8 |
| EP | kg $PO_4^{3-}$ eq. | 0.8 | 3.2E-02 | 0.1 | 1.7 | 0.0 | 2.6 |
| ODP | kg CFC11 eq. | 1.1E-04 | 3.4E-06 | 6.3E-06 | 1.7E-04 | 0.0 | 2.9E-04 |
| POCP | kg $C_2H_4$ eq. | 0.8 | 3.9E-02 | 0.1 | 1.4 | 0.0 | 2.4 |
| HTP | kg 1.4 DB eq. | 151.0 | 11.4 | 17.6 | 529.4 | 0.0 | 709.4 |
| TETP | kg 1.4 DB eq. | 3.2 | 0.3 | 0.4 | 11.9 | 0.0 | 15.8 |
| FAETP | kg 1.4 DB eq. | 50.8 | 3.2 | 4.8 | 152.2 | 0.0 | 211.0 |
| MAETP | kg 1.4 DB eq. | 3.4E+05 | 4.9E+04 | 5.9E+04 | 2.2E+06 | 0.0 | 2.6E+06 |

(1) GWP indicator in this case only accounts for the emission of $CO_2$ eq. associated with the system, while the potential $CO_2$ fixed as a consequence of cork oak forests is not considered in these results.

(2) Total represented the integrated FU: an initial tonne of raw cork material converted into its most representative products.

[12] Integrated FU: an initial tonne of raw cork material converted into their most representative products: 19% natural cork stoppers, 41% champagne cork stoppers, 7% white cork granulate, 7% black cork granulate and 26% of cork wastes.

### 7.3.5. Carbon dioxide balance of the cork sector and cork products

Besides provide cork and other goods, cork oak forests contribute to carbon dioxide fixation because trees grow for more than 200 years. The cork extracted represent only 4% of the carbon dioxide fixed [14], this carbon contained in cork products is considered carbon neutral in this study, as it is returned to the atmosphere within a short period [214, 215]. Carbon dioxide balance was discussed in previous research [203] finding that 18 t of $CO_2$ eq. are fixed per tonne of raw cork extracted in the forest. This value was calculated considering the emissions generated due to cork forest management, the carbon dioxide contained in cork products and a local $CO_2$ fixation rate [165].

Table 7.7 and figure 7.4 present the carbon dioxide balance for the integrated FU. Moreover, results could be observed divided by cork products. According to allocation rules, cork wastes generated besides cork products do not carry any environmental burden.

**Table 7.7 Carbon dioxide balance associated to an initial tonne of raw cork material converted into their most representative products**

| Environmental indicator | Total | Natural cork stopper | White cork granulate | Black cork granulate | Champagne cork stopper | Cork wastes |
|---|---|---|---|---|---|---|
| Reference Unit (kg) | **1,000** | 186 | 65 | 73 | 414 | 262 |
| GWP (kg $CO_2$ eq. emitted) | **3,359.4** | 683.5 | 54.2 | 78.9 | 2,542.9 | 0.0 |
| kg $CO_2$ fixed | **-18,000.0** | -12,384.0 | -504.0 | -2,016.0 | -3,096.0 | 0.0 |
| Global balance (kg $CO_2$) | **-14,640.6** | -11,700.5 | -449.8 | -1,937.1 | -553.1 | 0.0 |

Negative sign means that the carbon dioxide is fixed.

It can be stated that during the transformation of a tonne of raw cork to industrial products nearly 3,400 kg of $CO_2$ is emitted while 18,000 kg are fixed as consequence of these activities. The carbon dioxide balance associated with a tonne of raw cork converted into products was about 14,600 kg of $CO_2$ fixed. According to this result, cork sector could contribute to climate change mitigation. In fact, the balance is environmentally positive for all the products, but it is more favourable for natural cork stoppers and champagne cork stoppers because of the allocation rules established.

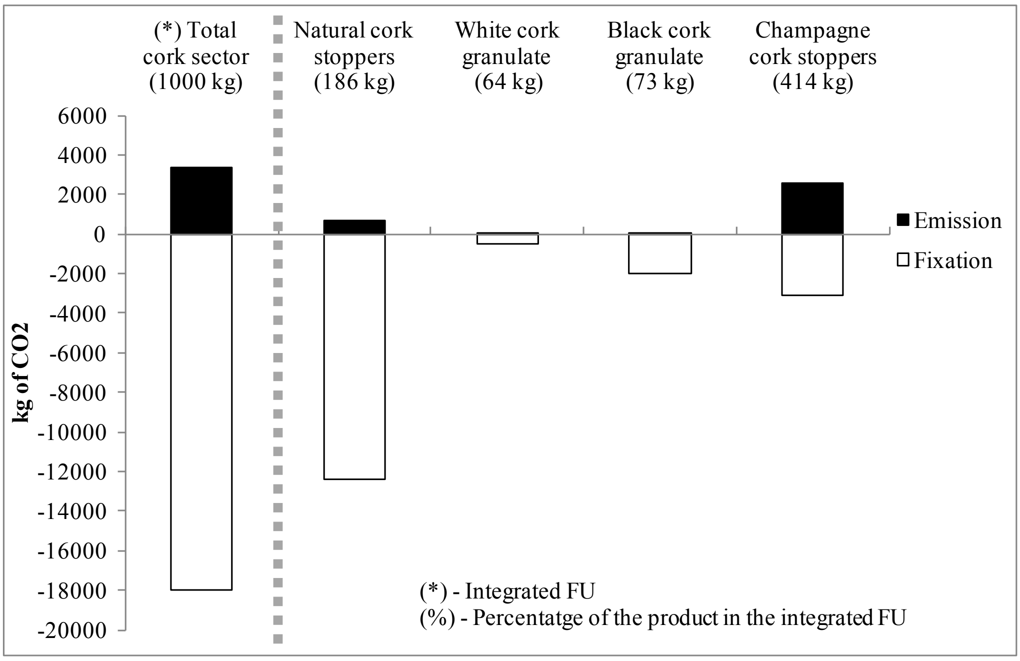



**Figure 7.4. Carbon dioxide balance of cork sector[13] in Catalonia, according to the percentage of each product from a tonne of raw cork material.**

Table 7.8 presents a carbon dioxide balance for natural cork stoppers and for champagne cork stoppers. Results are calculated from the allocation rules established in the project. From results, it can be outlined that besides generating a very useful product to protect the content of bottles, natural cork stoppers contribute to fix 234 g of $CO_2$ per stopper, while champagne cork stopper contribute to fix 12 g.

**Table 7.8. Carbon dioxide balance of natural cork stoppers and champagne cork stoppers.**

| Environmental indicator | Natural cork stopper | Champagne cork stopper |
|---|---|---|
| Unit reference | 1 stopper | 1 stopper |
| Weight of the product (g) | 3.7 | 9.0 |
| GWP (g $CO_2$ eq. emitted) | 13,6 | 55,3 |
| g $CO_2$ fixed | -247,7 | -67,3 |
| Global balance (g $CO_2$) | -234,1 | -12,0 |
| Negative sign means that the carbon dioxide is fixed. | | |

Different authors had found that GWP associated to a 75cl wine bottle was between 0.6 and 1.3 kg $CO_2$ eq. [176, 216-219]. The carbon footprint of wine bottles can be reduced by between 18-40% when a natural cork stopper is used.

[13] A tonne of raw cork is converted into: 19% natural cork stoppers, 41% champagne cork stoppers, 7% to white cork granulate, 7% black cork granulate and 26% cork wastes.

### 7.3.6. Regional Climate Change mitigation by cork sector

On one hand, as has been observed 14.6 tonnes of $CO_2$ were fixed as a consequence of integrated FU. Then, considering that Catalonia extracts 8-9 thousand tonnes of cork annually to be converted into cork products, this represented that cork sector contribute to mitigate between 116,800 – 131,400 tonnes of $CO_2$, besides generating cork products. The Catalan Climate Change Mitigation Plan for 2008-2012 [220] proposed to reduce the emissions of $CO_2$ by 5.33 million tonnes. The cork sector in Catalonia is helping to mitigate about 2.2-2.5% of these emissions considering only the cork extracted in Catalonia. This result demonstrates the importance of local carbon dioxide mitigation strategies.

Assuming the results found and extrapolating them to a world scale where 300,000 tonnes of raw cork are produced annually [18]; the worldwide cork sector contributes to the mitigation of about 4.38 million tonnes of $CO_2$, apart from generating cork products. Most of this mitigation takes places in the Iberian Peninsula where more than 85% of the world's cork is extracted [18].

### 7.3.7. Sensitivity analysis of the allocation rules established

ISO 14041 [110, 136] states that (a) whenever possible allocation should be avoided by increased level of detail or system expansion, (b) when it cannot be avoided, environmental burdens should be partitioned among its different products or functions according to the physical relationships between them, and (c) when a physical relationship cannot be used as a basis for allocation, other relationships can be considered [134]. Allocation rules are very important because different results could be obtained in systems where open-loop recycling systems are considered [135]. Allocation procedures are one of the most controversial and heavily discussed topics in LCA methodology [135, 136, 199-201, 221].

This section tries to evaluate how the allocation rules affect the results. Specifically, the GWP indicator and the carbon dioxide balance will be tested. The allocation rules established in the study (A1 – table 7.7) will be compared with mass allocation rules (A2 – table 7.9). The second approach is based on the perspective that natural cork industries have an efficiency of nearly 30% with their raw cork material, and therefore impacts of natural cork products should be divided between the product and by-products generated. In addition, impacts could be also distributed according to economic relationships. However, due to the very low price of cork industry wastes compared with natural cork products, results obtained should not differ greatly from the approximation established in the reference study (A1). Table 7.9 presents the comparison for both approaches.

**Table 7.9. Sensitivity analysis of allocation rules established in the environmental analysis of cork products: environmental burdens established according to mass balance.**

| Environmental indicator | Total | Natural cork stopper | White cork granulate | Black cork granulate | Champagne cork stopper | Cork wastes |
|---|---|---|---|---|---|---|
| Reference Unit (kg) | **1,000** | 186 | 65 | 73 | 414 | 262 |
| GWP (kg $CO_2$ eq. emitted) | **3,359.4** | 205.0 | 118.8 | 78.9 | 2,956.7 | 0.0 |
| kg $CO_2$ fixed | **-18,000.0** | -3,715.2 | -1,674.3 | -2,016.0 | -10,594.5 | 0.0 |
| Global balance (kg $CO_2$) | **-14,640.6** | -3,510.2 | -1,555.5 | -19,37.1 | -7,637.8 | 0.0 |

Negative sign means that the carbon dioxide is fixed.

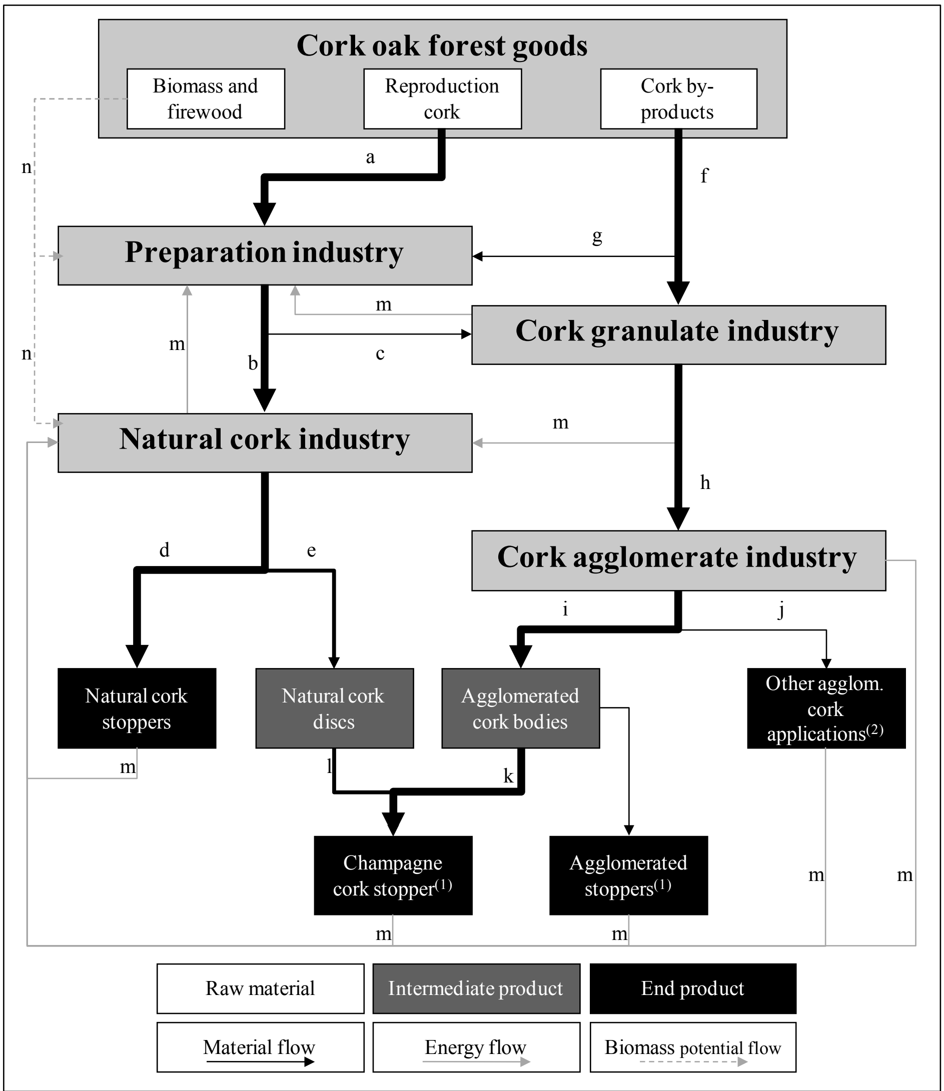
Results for the integrated FU from both approaches are the same. However, A1 is more favourable for the natural cork stopper; while the A2 approximation was inverse; and results were more favourable for champagne cork stoppers and white cork granulate. The two approaches are valid, but a conflict of interests appears. It is clear that if only the carbon dioxide balance is considered a producer of natural cork stoppers will prefer the first approach, while a champagne cork industry will prefer the second. However, considering the other potential impacts, or only considering GWP emissions, it will be reversed.

From this sensitivity analysis it can be found that despite the system expansion being carried out as often as advised [134, 222], the arbitrary nature of how to distribute impacts continues. Consequently the authors have to make choices about what model or approximation is better. It is clear that allocation is one of the methodological aspects of LCA that should be improved in the future in order to guide LCA practitioners to perform quality research.

## 7.4. Discussion

One of the main characteristics of the cork sector is that many flows interconnect different subsystems or are even recycled into the same subsystem. In some way, it can be assured that the cork sector always tries to optimise its most valued raw material - cork. It is for this reason that cork waste from natural cork stopper production is transformed into cork granulate, or why cork dusts generated during the size correction operation in natural cork stopper production can be used within the same system in the boiling operations as a renewable energy source. More examples can be found, as illustrated in figure 7.5. Some of these exchanges are happening today and considered in the environmental results, while others are potential projects for and among actors in the cork sector. To reuse and optimise cork flows could mean significant improvements from an industrial ecology point of view.

The cork sector has potential interconnections, but often they do not occur because different companies, or actors, take part in the exchange process. The interconnection of flows that are not happening are caused because of individual interests or because of an insufficient information interchange among companies.




(1)**Champagne cork stopper** is the most representative **technical stopper** formed by two natural cork discs and an agglomerated cork body. A huge diversity of technical cork stoppers exist: with or without natural cork discs such as for example **agglomerated stoppers**.
(2)In Catalonia, other cork agglomerate applications different from generating technical stoppers represent only a minor part of the market. They represent less than 2% of the total cork sector bill. However, these applications seem set to become more significant in the future if the sector wants to diversify production.

a. reproduction cork slabs to prepare.

b. prepared cork slabs to natural cork industry.

c. rejected cork from preparation to cork granulate.

d. prepared cork slabs transformed to natural cork stoppers.

e. prepared cork slabs (> 27 mm thickness) transformed to natural cork discs.

f. cork by-products intended to become black cork granulate.

g. cork by-products intended to manufacture white cork granulate.

h. cork granulated send to cork agglomerate industry.

i. cork agglomerate transformed to agglomerated cork bodies.

j. cork agglomerated transformed to diverse applications (floorings, decoration objects, construction panels...).

k. agglomerated cork bodies joined with natural cork discs to produce champagne cork stoppers.

l. natural cork discs and agglomerated cork bodies joined to produce champagne cork stoppers.

m. stoppers and other products recycled as energy source.

n. biomass and firewood from forest could be used for boiling operations in preparation in natural cork industries.

**Figure 7.5. Cork sector potential flows interconnection.**

The natural cork stopper is the key element in cork sector because is the product with highest added value, while champagne cork stopper is also key from an industrial ecology perspective because this product is an example of symbiosis between cork subsystems because it recycles material from the natural cork industry. In fact, the champagne cork stopper is an unconscious environmental strategy of the cork sector as it is a product generated out of the optimisation of a raw material.

The experience in the cork sector during the period 2008-2011; including several seminars, workshops and fieldwork with cork stakeholders; and the present research; permit us to suggest some environmental strategies to improve the whole cork sector from an industrial ecology perspective. Table 7.10a and 7.10b summarise many potential strategies that can be applied to advance sustainability of the cork sector grouped by the following systems: forestry, industry, natural cork stopper subsystem, champagne cork stopper subsystem, granulate cork subsystem and cork sector organisation. Furthermore, the current degree of implementation and the degree of difficulty to implement the strategy is qualitatively pointed out. In future, these and other alternatives should be considered and systematically assessed in order to quantify and determine how impacts could be reduced for each case.

**Table 7.10a. Environmental strategies for cork sector improvement.**

| SYSTEM | STRATEGY | (1) | (2) | (3) |
|---|---|---|---|---|
| FORESTRY | Biomass and firewood from nearer cork oak forests could be used in cork industries as renewable source of energy | ↓ | ↓ | - |
| | Certification of raw cork material for quality assurance and help preserve cork oak forests | ↓ | ↓ | - |
| | Optimise the transport of workers into cork oak exploitation sites during forest management | ↓ | ↑ | - |
| | Improve cork stripping stage and especially the cork's movement from the road to the meeting point operation. | ↓ | ↑ | - |
| | Combine cork extraction with other forest goods extraction and services. | ↓ | ↓ | - |
| INDUSTRY | Optimise symbiosis of cork subsystems. | ↓ | ↓ | - |
| | Maximise the cork raw material and reduce 26% of cork wastes generated per tonne of cork products. | ↓ | ↓ | - |
| | Use of cork wastes for other low added-value applications existing (sawdust, shoe insoles, etc.) | ↑ | ↓ | - |
| | Generate new high-added value products (aerospace, automobile, furniture, etc.) | ↓ | ↓ | - |
| | Preferably use of local raw cork | ↑ | ↑ | - |
| | Avoid dividing production between different production plants. | ↓ | ↑ | - |
| | Minimise and ecodesign packaging of the products | ↓ | ↓ | - |
| | Use of green electricity instead of conventional electricity | ↓ | ↓ | - |
| | Use of solar or wind source of energy instead of conventional electricity. | ↓ | ↓ | - |
| | Installation of a collective cork sector plant to generate electricity from cork dusts and biomass. | ↓ | ↑ | - |
| | Reduce the consumption of fresh water in boiling and washing operations. | ↓ | ↓ | - |
| | Not exceed the quantities of auxiliary materials recommended by providers. Optimise inputs. | ↑ | ↓ | - |
| | Substitute diesel oil in boiling operations by renewable sources of energy (cork dust, biomass) | ↓ | ↓ | - |
| NATURAL CORK STOPPER SUBSYSTEM | Use of industrial cork wastes from natural cork products to generate cork granulates. | ↑ | ↓ | - |
| | Improve the manufacturing stage of natural cork stopper production from a cleaner production perspective, and specially the punching into cylindrical pieces, size correction and second boiling operations. | ↓ | ↑ | - |
| | Maximise cork raw material to obtain as many natural cork stoppers as possible. One interesting option is to manufacture natural colmated[14] cork stoppers. | ↑ | ↑ | - |

**(1) Current degree of implantation (↑ High / ↓ Low)**
**(2) Difficulty of implantation (↑ Difficult / ↓ Easy)**
**(3) Reference ( - proposed by authors)**

[14] Natural colmated cork stoppers are natural cork stoppers of very low quality that are recovered externally by cork dusts and glues in order to reduce porosity of the product.

**Table 7.10b. Environmental strategies for cork sector improvement**

| SYSTEM | STRATEGY | (1) | (2) | (3) |
|---|---|---|---|---|
| CHAMPAGNE CORK STOPPER SUBSYSTEM | Research and improve the manufacturing stage of champagne cork stoppers, and especially the glue of discs and body agglomeration operations. | ↓ | ↑ | - |
| | Preferably use natural glues for agglomerated products. Research new glues options. | ↓ | ↓ | - |
| | Reduce the quantity of electricity consumed during the production of champagne cork stopper. | ↑ | ↑ | - |
| CORK GRANULATES SUBSYSTEM | Improve the manufacturing stage of cork granulate products | ↓ | ↑ | - |
| | Generate granulate cork products with high economic added-value | ↓ | ↑ | - |
| END-OF-LIFE | Use cork dusts as a renewable and local source of energy, when the generation of cork products is completely impossible. | ↓ | ↓ | - |
| | Recycling of cork products after their end-of-life giving a second life for cork material or at least, use it as fuel. | ↓ | ↓ | [70] |
| | Cork stoppers could be also composted with organic matter. | ↑ | ↓ | [223] |
| | Cork wastes could also be used for removal and decontamination of Lead and Polonium from the natural environment | ↓ | ↓ | [224] |
| CORK SECTOR ORGANIZATION | Create an organisation of cork oak owners in order to increase internal communication. | ↓ | ↓ | - |
| | Improve data collection systems in order to facilitate future research | ↓ | ↓ | - |
| | Articulate better cork sector organisation. | ↓ | ↓ | - |
| | Collaboration and sharing between all cork actors at different levels: internal and external sector diffusion, training courses, common research, | ↓ | ↓ | - |
| | Transport of raw materials shared with other companies. | ↓ | ↑ | - |
| | Distribution of cork products shared with other companies. | ↓ | ↑ | - |
| | Management share for different tasks: waste management, laboratory tasks, quality controls tasks, so on. | ↓ | ↓ | - |
| | Development of an eco-industrial park (EIP) for the cork sector. EIP also allows for other initiatives at a higher scale. | ↓ | ↑ | [225-227] |

**(1) Current degree of implantation (↑ High / ↓ Low)**
**(2) Difficulty of implantation (↑ Difficult / ↓ Easy)**
**(3) Reference ( - proposed by authors)**

Many other environmental strategies for the development of the cork sector could be found, and they could also be shared with other sectors (furniture, automotive, construction, etc.). In fact, as cork could be used for many functions and applications, many combinations are possible. The industrial symbiosis could contribute to greening current systems, and even reducing costs to make the cork sector more competitive.

As the cork sector is localised geographically in a specific area; this is an excellent opportunity for collaboration among different cork actors: companies, forest owners and institutions. In fact, a cork cluster is developing because of collaboration facilities. The establishment of an EIP for the cork sector is a good idea for future organisation that will make the sector more competitive. The creation of an EIP could only be done if regional institutions opted for this strategic sector promoting, financing and subsidising investments.

## 7.5. Conclusions

- From a tonne of raw cork from the forest, approximately 50,000 natural cork stoppers (186 kg), 46,000 champagne cork stoppers (414 kg), 65 kg of white cork granulate, 73 kg of black cork granulate and 262 kg of cork wastes can be generated. The better the quality of the cork, the more natural cork stoppers are obtained, and consequently more income.
- The analysis of environmental impacts of the four products by stages resulted that industrial stages contribute more to the environmental impacts than forestry management. Specifically, for all the products, the manufacturing stage was the one which contributed most. The improvements proposed from a cleaner production perspective in previous industrial life-cycle assessment studies [157-159, 203] are also completely justified from an integrated point of view.
- The forestry management stage is important for the black cork granulate system where it contributed between 9-51% depending on the category analysed, and for a natural cork stopper's life-cycle where it contributed between 10-25%. The relatively low importance of the forest management stage; and the complexity of its study; make us recommend the use of data obtained in [203] for future studies of the sector.
- Transport from the forest is the only significant impact for the natural cork stopper life-cycle system because an important part of the raw material originates in the southern part of the Iberian Peninsula as there is insufficient raw cork material in Catalonia to satisfy the industry's demands. For cork granulate, the transport of the raw material had a lower importance because it was on a local scale as the import of raw cork to produce granulates is economically unviable because these intermediate products have very low-added value and costs would be higher than benefits.
- A tonne of raw cork in forest transformed into products generates emissions of about 3.4 tonnes of $CO_2$ eq., while the fixation is about 18 tonnes of $CO_2$. Consequently, besides generating a product, the cork sector contributes globally to fix 14.6 tonnes of CO2. Subsequently, cork and the cork sector generally can help to mitigate climate change by reducing the carbon footprint of products that use this type of closures.
- It is stated that the carbon dioxide balance associated to natural cork stoppers was 234 g of CO2 fixed per stopper, and 12 g of $CO_2$ per champagne cork stopper.
- A sensitivity analysis demonstrated that the environmental impact of the integrated cork sector would be similar to that found if mass relationship was used for environmental burden distribution, while distribution of impacts by

products would change generating conflicts of interest between the different cork subsectors. It was found that allocation rules were one of the most complex and controversial points in LCA.

- It is stated that many cork flow exchanges are possible within the cork sector, but in some cases the symbiosis is not occurring because of individual interests or because of a lack of awareness that neighbour companies have these resources available.
- Table 7.10a and 7.10b propose and evaluate qualitatively several strategies to improve the cork sector from an industrial ecology point of view. Some of these strategies are: (1) to use renewable sources of energy when possible: biomass, cork dusts, solar, wind; (2) to generate new cork products with higher added value; (3) to preferably use of local resources; (4) to optimise manufacture stage of the products, (5) to improve the general grade of organization of the sector; (6) to maximise symbiosis among subsystems and actors; (7) to reduce and use recommended doses of auxiliary materials; (8) to reuse or recycle cork products after their end-of-life; (9) to develop an eco-industrial park (EIP) associated to the currently developing Catalan Cork Cluster. Strategies must be assessed in future research in order to evaluate its viability economically, environmentally and socially.

# PART V

## CONCLUSIONS AND FUTURE RESEARCH

Conclusions and future research

# Chapter 8

# CONCLUSIONS AND FUTURE RESEARCH

**Chapter 8** addresses the main research findings and formulates a list of general final comments, based on the objectives established and extended conclusions presented in Chapters 3 to 7. This thesis presents an integrated environmental analysis of cork sector in Western Europe (Catalonia) by using a life cycle approach. Also, future research will be presented in order to remark which aspects must be done preferably from our point of view.

This chapter is structured as follows:

- Conclusions
- Future research

# 8. Conclusions and future research

## 8.1. Conclusions

The following section describes the main conclusions derived from the present thesis. Methodological aspects will be presented and commented, and then cork sector findings will be outlined according to the objectives described in Part I.

### 8.1.1. Methodological aspects

The methodology used in the thesis was found to be adequate, as was the approach to the cork sector through analysis of its individual parts and their final integration. Also, seminars, workshops and fieldwork were very useful for developing the questionnaires to a highly accurate degree of detail which, after processing, will became sectorial inventories, and sectorial impact assessments of products. The following outcomes associated to **data collection processes** were obtained:

- The data collection process followed resulted appropriate. As the information requested was very detailed, results and conclusions were very interesting. Otherwise, the degree of detail also translated into greater complexity of research, and in particular the calculations became more difficult and required more time and effort.
- The drawing-up of individual questionnaires for each subsystem was a creative task, because each company had its own production method and its own sources of information in different units. A homogeneous, flexible and adaptable questionnaire was created.
- The questionnaire developed for each subsystem was very helpful, but a lot of guidance to companies was necessary, as well as fieldwork, to obtain the desired information for each one. In fact, although the questionnaire was presented in a particular seminar, it was necessary realize fieldwork company by company in order to offer individual explanations for the entire questionnaire. Also, the fieldwork was very interesting for auditing each company, collecting indirect data and verifying the information given. For future similar studies, it would be very helpful to add a specific guide to describe how to complete the questionnaire.
- Data collection verification by ICSuro and CFC was very useful for filtering and checking information. Also, studying more than one company or forestry owner facilitated comparison, and consequently, verification of the data obtained.
- The same data collection process, and similar industrial questionnaires, used for the cork sector could be used for other sectors, by adapting tables to specific processes for the products to be analysed.
- Also, the *Cork Oak forest Management questionnaire* could be used to assess the cork sector in other extractive regions. And additionally, this questionnaire

could be adapted for environmental assessment of other extractive agro-forestry systems.

LCA was a very good sustainability tool to assess the cork sector and its subsystems. It is recommended for future sector assessments. The main contributions of the present thesis associated to LCA were:

- One of the most important methodological contributions is that the cork sector has been evaluated using LCA from a sectorial perspective instead of the evaluation of a particular industry. The results are indicative of the environmental state of the current cork sector in Catalonia, and are applicable to other areas of the world.
- The use of LCA methodology to evaluate a system with a life span of over 200 years was a *priori* very complex. However, it was tackled by dividing the system into similar systems of 13 years, reducing the difficulty of data collection. In addition, as the model of cork exploitation in Catalonia is based on natural regeneration and the fact that cork oak forests are divided into 13 similar parts, data about the activities performed during last year could be collected. This was possible because it was observed that three exploitation plots are managed on an annual rotating basis: cork is extracted in one, it is scratched in another and the third remains under general forest maintenance. As a result of this approach, the complexity of the system was reduced and forestry cork sector could be assessed properly.
- One particular aspect that could not be considered because of the unavailability of data was the $CO_2$ fixation of the tree according to tree age. The fixation should have been estimated from local bibliographic data that considers a constant fixation of the tree over time.
- Although a *priori*, cork products seem very simple this is not the case. The numerous stages, operations and processes that take place during their production demonstrate this. More than 20 processes for each product were considered (Annex I).
- LCA was very useful for detecting the weaknesses in the cork sector as a whole and in its subsystems.
- System expansion was a good approach for avoiding allocation procedures because it allowed coherent systems and subsystems to be established. Assessment of a sector would permit system expansion, whereas when only the product is assessed, cut-off method is often necessary. Although system expansion was carried out in integrated system evaluation, cut-off method should be used to distribute impacts among products, by-products and waste. Allocation procedures used in the study were found to be adequate.
    - → Integrated cork sector results would be the same as those found if other allocation was considered. However, distributing impacts between cork products and by-products according to physical or economic relationships affected the results, and was one of the most controversial points involving authors choices and decisions. This is

very clear for the impacts distribution between natural cork stoppers and champagne cork stoppers; using different allocation rules would mean a transfer of impacts from one system to the other.

→ The decision was taken to allocate all the environmental burdens to the product desired for the analysed cork subsector, while by-products and waste coming from previous systems were allocated without any environmental impacts.

→ During the thesis different sensitivity analyses were performed in order to test possible allocation rules and scenarios.

- One important aspect related to LCA methodology was that some important environmental aspects such as water footprint, soil erosion, desertification and biodiversity have not been evaluated and are very important from a Mediterranean perspective.

## 8.1.2. Cork subsectors aspects

The evaluation of the cork sector in Southern Europe (Catalonia) has offered a range of inventory and impact assessment data for future case studies and also for databases. According to the bibliography, cork has physical and chemical properties that make it an ideal raw material for many applications. In addition, the present thesis has highlighted that cork is an excellent material from an environmental point of view. In the following section the main outlines of each cork subsystem assessed in the thesis are described:

### *Forestry cork subsector*

- It was found that cork presented a low environmental impact: 0.2 t of $CO_2$ eq. were emitted for each tonne of raw cork as a result of extraction and forest management; considering a production yield of 150 kg/ha/year.
- The raw cork presented a high $CO_2$ fixation per FU. It was calculated that 18 t of $CO_2$ were fixed as consequence of the extraction of a tonne of raw cork, discounting the emissions associated with their extraction, and the carbon contained in cork products (considered carbon neutral).
- It was detected that transport of workers and cork within forest to carry out the different management activities associated with cork extraction were the operations with the greatest impact on the subsystem, causing between 82-94% of all the environmental impacts. So, if the forestry cork sector is to be improved from a cleaner production perspective, these transport operations should be reduced or optimized. However, this is difficult to achieve due to the nature of the system since territorial characteristics and the particularities of exploitation condition internal transportation.
- Some authors have pointed out that the quantity of cork extracted in Catalonia could be doubled if the cork oak forests that are not currently exploited began to be managed. This aspect is environmentally important because about 75% of the raw cork used to manufacture cork products in Catalonia is extracted in Portugal or Southern Spain. Using a larger quantity of locally-extracted cork could contribute to reducing the environmental

impact of the cork sector, and would also improve the management of cork forests.

- A sensitivity analysis of cork yield production showed that the higher the cork forest productivity (200 kg/ha/year) the lower is the associated environmental impact: 25% less than for the reference (150 kg/ha/year). On the other hand, very low productivity (50 kg/ha/year) represented 3 times the impact on the reference considered.

## *Industry cork subsectors*

The environmental impacts associated with the production of different cork products in Catalonia had been quantified: natural cork stoppers, champagne cork stoppers, white cork granulate and black cork granulate. Two general outcomes were found:

- As there was no official BAT reference document for cork products manufacture, the present thesis could be the first approach.
- During the thesis, the operations which contributed most to the environmental impact of each subsystem —the weak points— were detected for each industrial subsector.

The following sections describe the main findings for each cork subsector.

**Natural cork stopper subsector**

- It was found that 116 kg of Sb eq., 10,947 kg of $CO_2$ eq., 101 kg of $SO_2$ eq., and 14 kg of $PO_4^{3-}$ eq., were emitted during the industrial production of a million natural cork stoppers (FU).
- The manufacturing stage was that which should preferably be ecodesigned because it contributes between 34-65% for all the categories analysed, and concretely the punched into cylindrical pieces, size correction and 2nd boiled operations.
- Transport of raw cork from the forest contributes significantly to the environmental impacts, more than 20% in all the categories except for MAETP, and for this reason using local cork would be preferred because the environmental impact of the product could be significantly reduced.
- Also, the finishing stage has a significant contribution in the overall impact of the subsector, between 10-27% of all the impacts. Most of these impacts are caused because of washing-drying, colouring and packaging operations that it is recommended could be improved.
- End-of-life stages represent at most 3% of the impacts, while distribution of products contributed between 3-9% of all impacts depending on the category. Consequently, changes in these stages would mean an insignificant reduction of the impacts.

- It was stated that the worst producer generates an emission between 3.1-7.2 times greater than the best producer. These differences are very significant and demonstrated clearly that natural cork stoppers producers have the opportunity to improve their production just by implementing available technology and technical practices that other companies of the sector has already implemented. The heterogeneity of data among producers indicates clearly that this subsector had an important potential to improve environmentally.

**Cork granulate subsector**

- It was found that about 5 kg of Sb eq., 770 kg of $CO_2$ eq., 6 kg of $SO_2$ eq., and 0.5 kg of $PO_4^{3-}$ eq., were emitted during the industrial production of white and black cork granulates (FU). Very similar results are observed for both flows because the same production process is performed for both.
- More than 90% of all the environmental impacts of white and black cork granulate were the result of trituration and classification-sieving operations. Technical improvements in these operations will reduce the impacts very notably.
- Transport of cork waste and cork by-products represented less than 4% of the environmental impacts for both cork granulates. In addition, the preparation of cork associated with white cork granulate contributed less than 3% for all categories.
- Practically 35% of the cork that enters the system became triturated cork waste with grain size of less than than 0.25 mm. At the moment, this raw material is only used as energy in the biggest companies or as a filling agent for *colmated cork stoppers*. This material could be used in innovative new cork applications.

**Champagne cork stopper subsector**

- It was found that 406 kg of Sb eq., 53,886 kg of $CO_2$ eq., 430 kg of $SO_2$ eq., and 36 kg of $PO_4^{3-}$ eq., were emitted during the industrial production of a million champagne cork stoppers (FU).
- The champagne cork stopper manufacture stage was the one in which most pollution was produced: between 57-67% for all the categories. It was especially the result of body agglomeration and disc gluing operations.
- The granulate manufacture stage had a contribution of between 11-15% of all the impacts, while finishing stage and discs manufacture contributed between 6-10%.
- Many of the stages contributed less than 2%: transport of the raw material from the forest, cork preparation, transport of discs, transport of granulate, distribution of the product and end-of-life stages.
- It was seen that implementing the best champagne cork stopper manufacture stage of the best company in the sector average, would reduce the global environmental impacts between 11-41%, depending on the considered category.

- It was observed that the worst producer generates impacts of between 1.3 and 1.7 times higher than the best when producing the FU. These results was more homogeneous than for natural cork stopper, and indicated that although environmental improvement is possible, it will not be as significant as for natural cork stoppers producers.

### *Transports of cork sector*

Transports within the cork sector were also analysed through the study of the main cork products:

- It was observed that for natural cork stoppers, an important part of raw cork should be imported from Portugal and Southern Spain, because the Catalan cork industry subsector requires more raw material than Catalan cork oak forest subsystem can generate. The impact associated with cork importation was attributed only to the natural cork industry because it only took place as consequence of this subsector.
- It was recommended that, preferably, cork extracted in Catalonia be used because since the transport would be local, the environmental impacts associated with natural cork stoppers would be reduced. In fact, the production of a natural cork stopper in the current average sector results considering an average transport of 741 km[15] emitted 10.9 g of $CO_2$ during their industrial cycle, while a production of a stopper produced locally[16] emitted only 7.7 g., which is about 30% less impact.
- It was observed that cork granulates are practically always manufactured from cork by-products of Catalan cork forests or by waste generated in natural cork industry in Catalonia. Then, local transport was associated to the lower price that this intermediate product had, because regional or international transport for this purpose could mean greater costs than their sale price.
- It was recommended that cork products be manufactured near the areas where the raw material is extracted and only final products transported in order to minimize environmental impacts and reduce economic costs. Transport of raw material from long distances is discouraged.

## 8.1.3. Integrated cork sector evaluation

This dissertation has permitted the integrated evaluation of cork sector from an IE perspective, by using a life-cycle approach. After analysing each cork subsector, the integrated scope allowed to determine greener and global strategies to recommend cork sector in order to continue advancing towards sustainability. The following findings were found from the integrated point of view:

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[15] 741 is the average distance of a million natural cork stoppers in Catalonia. This distance was considered averaging data of the industries analysed and their flows of raw material.

[16] Considering a distance of 100 km.

- From a tonne of raw cork from the forest the following cork products and cork waste were obtained: 186 kg of natural cork stoppers, 414 kg of champagne cork stoppers, 65 kg of white cork granulate, 73 kg of black cork granulate and 262 kg of cork waste.
- It was noticed that the percentage of white and black cork granulates remaining for products other than natural cork stoppers and champagne cork stoppers is quite low.
- It was found that the forestry cork stage has a low-impact contribution in the cork sector compared with other industry activities in the same sector. It contributed between 10-25% to the natural cork stopper subsystem, when the cradle-to-grave system is considered. It was stated that because of low incidence during this stage and the complexity of studying it, data obtained in this thesis is recommended for use in future case studies.
- Integrated results pointed out that, globally, the cork sector contributed to the fixation of carbon dioxide in addition to making cork products. In fact, the balance showed that 14.6 t of $CO_2$ eq. were globally fixed per each tonne of raw cork that is transformed to cork products, contributing to mitigate climate change.
- The Catalan Climate Change Mitigation Plan for 2008-2012 [220] proposed to reduce the emissions of $CO_2$ in 5.33 millions of t; consequently, the Catalan cork sector is helping to mitigate about 2.2-2.5% of these emissions, considering only the cork extracted in Catalonia; about 8,000-9,000 tonnes annually (between 116,800 – 131,400 t of $CO_2$). Local and regional strategies for climate change mitigation are very interesting and have a significant effect.
- Assuming similar results to those found in this research for a tonne of raw cork converted into products, about 4.38 m tonnes of $CO_2$ are mitigated thanks to the 300,000 tons of raw cork yearly produced in the world.
- Cork and cork products could help to reduce the carbon footprint of other products. This is important for natural cork stoppers, which are part of still wine bottles packaging and are a better solution, from an environmental perspective, than other competitors made of scarce minerals or petroleum derivates. It was calculated that 234 g of $CO_2$ were fixed per natural cork stopper, and 12 g of $CO_2$ were fixed per champagne cork stopper. Considering that GWP associated with a wine bottle of 75 cl was between 0.6 and 1.3 kg $CO_2$-eq, using a natural cork stopper could reduce the carbon footprint of wine bottle between 18-40%. Consequently, the use of cork stoppers could be a strategy to reduce the environmental impacts in the wine sector.
- If the $CO_2$ fixed by stoppers had been allocated according to relationships of mass, the results would have been different than those that were found. Consequently, 63 g of $CO_2$ would have been fixed per natural cork stopper and 166 g for each champagne cork stopper.

### 8.1.4. Cork sector global improvement proposals

Many different strategies to globally and environmentally improve the cork sector were found (tables 7.10a and 7.10b). In this section, the most significant and advisable strategies are commented on.

- It was stated during the integrated evaluation that cork sector had started to optimize its systems unconsciously and without systematization. In fact, cork granulates and the body of champagne cork stopper were a solution to recycle raw cork materials that were not able to be used as single pieces of cork. In some ways, champagne cork stopper is a very important product from IE perspective, because it integrates forest by-products and industrial cork waste and allows to take profit of some materials considered to be waste of other subsectors.
- It was noticed that many flows of cork were recycled internally in the same factory or even sold and recycled by other industries or subsectors: this is, for example, the case of natural cork stopper waste, which most part goes to granulate manufacture subsystem. However, it was found that the optimization of these systems had a great potential yet, as well as the improvement of the symbiosis cycles.
- An improvement for the cork sector could be the reduction of the current 262 kg of cork waste that are generated after converting a tonne of raw material in cork products. For this purpose it is necessary to take advantage of this raw material, which is barely done. Different strategies could be found for this cork waste, they are presented prioritized:
    - → Maximize the efficiency of the raw material as much as possible in order to raise the production while reducing the amount of cork waste.
    - → Produce new cork products with this flow. It should be taken into account that this material would be mostly triturated and with particles below 0.25 mm, and this can imply technical difficulties.[17]
    - → When it is not possible to use this material it could be used to substitute non-renewable fuels such as diesel oil. This practice was very little implanted and only biggest companies had started to implement it. It has a very high potential. One option to decrease investment costs could be incorporating a collective plant to generate electricity from these cork waste, or even use biomass from near forests generated by the forest management.
- Generating new cork products with higher added value could be a strategy interesting in order to diversification the production and not depend exclusively on stoppers.

[17] Fine particles below 0.25 mm are considered cork dust and it is difficult to use them to generate cork products. As they are very small particles with a very high specific area, large amounts of glue are required to manufacture products from this material, making it not economically viable.

- Symbiosis of cork sector was happening, but there is a lot of potential in increasing the grade of collaboration among companies. One of the weaknesses of the sector that had been detected was that cork sector level of organization can be raised notably.
    - → This is significant for the communication between companies because often they do not know that some waste from their processes could be useful for their neighbours. In some cases, they have to manage these flows as waste and consequently pay for their disposal, while some of their neighbours could be interested in buying these flows and using them as raw material for their products or as energy source when they have implemented the associated technology.
    - → In addition, the level of communication among cork forest owners is really very low, and it is fundamental to increase communication networks. ICSuro and CFC had the opportunity to integrate more cork actors in the sector.
- Localizing all the stages of the production in the same factory would delete intermediate and unnecessary transportation of flows, and would contribute to reduce impact.
- Reusing or recycling cork products after their useful life was an interesting strategy to retard the end-of-life of the products. Used cork stoppers could be granulated and reused to make non-food products (aerospace or automobile pieces, insulators or construction panels, among other uses).
- The fact that the entire cork sector and all its actors are concentrated in a geographical area smaller than 100 km in diameter in the north of Catalonia reflects the fact that these days the sector is developing a specific cluster. This condition is also a very good scenario to develop an eco-industrial park (EIP) associated to the current developing Catalan Cork Cluster.

## 8.2. Future research

In this section, future research will be addressed.

- Cork institutions should collect, and supply, more basic information on a yearly basis such as: quantity of cork produced, origin of each raw cork, number of cork stoppers produced by type, number of other cork products produced, updated register of companies and cork oak forest owners, etc. Introducing information management tools could be useful to perform future quality research.

The following methodological aspects are advised for research to complement the present thesis:

- Assessment of other environmental aspects associated to cork oak forests that are being developed in LCA methodology: biodiversity, soil erosion, desertification, and so on.

Some research recommended for the forestry system:

- It would also be interesting use LCA methodology to evaluate whether a cork certified by PEFC or FSC has a lower impact than one which is not certified.
- Studying $CO_2$ fixation by cork oak in depth is necessary. In particular, it is very interesting to analyse $CO_2$ fixation depending on the tree ages in order to analyse the entire fixation of the cork oak life cycle.
- Economic quantification of cork forest services would be a good complement for the present thesis. Ecoefficiency studies would also be very interesting.
- Studying the cork oak agro-silvicultural extraction system in Southern Spain and Portugal to complete the environmental evaluation of cork sector in the most cork-productive areas in the world.

According to the study of the industry subsystem, it would be very interesting to make an in-depth study of the following topics.

- Calculating the carbon footprint of cork products according to PAS 2050 [228], and the water footprint.
- Carrying out a research about cork sector transport and logistics.
- Some of the very specific aspects that were excluded from production subsystems should be studied in the future in order to analyse their relative importance:
  - → Flows in small quantities (less than 2%) such as colourings, inks and detergents used in industry subsector.
  - → Wastewater generated during boiling and washing operations. It is necessary to carry out wastewater analysis, because these were not available during the thesis.
- Planning and evaluating specific cleaner production strategies. For this purpose it would be necessary to perform pilot experiments to compare two

or more technologies for the operations of the industrial cork subsector production with the highest impact. Later, those different options should be assessed environmentally and technically in order to assure the highest production with the lowest impact. Some examples are:

→ Washing by aspersion instead of washing by bath.

→ Rigorous initial selection of raw cork material in the forest instead of the current selection

→ Introducing in natural cork stopper production a stopper selection operation after being punched into cylindrical pieces in order to remove stoppers that would otherwise be removed in later stages after having gone through several other operations. This same practice could be introduced for natural cork discs production.

→ Using ecological glues instead of the current tendency of using polyurethanes for the champagne cork stopper production.

→ Different options of packaging and distribution of final products.

- Strategies proposed in the integrated evaluation of the sector must be assessed in future research in order to evaluate their viability from an economic, environmental and social perspective.

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# Annex I. Questionnaires

Annex I presents two of the questionnaires that were used to collect data from the cork sector subsystems. First, the *cork oak forest management questionnaire* is presented in order to show how information was elicited and structured. Following this, the *natural cork stopper questionnaire* is presented. It was decided not to add the *cork granulate questionnaire* and the *champagne cork questionnaire* because they were very analogous to the *natural cork stopper questionnaire* due to a similar methodological approach, and it was considered more suitable to include just one example of an industrial questionnaire. Before completing the questionnaire, all those operating in the cork sector were sent information and instructions (Table AI.1), in order to define basic parameters and establish a common language.

**Table AI.1. Basic information for questionnaire fulfillment**

| Apartat | Descripció |
|---|---|
| - Finca / Empresa / Municipi d'origen | Cal especificar el nom de la finca / empresa / municipi d'origen o destí. |
| - Finca / Empresa / Municipi de destí | En el cas de que es comprin productes semielaborats (taps de suro fabricats per acabar, discs de suro natural, planxes ja bullides, etc. S'ha d'indicar l'empresa fabircant i les seves dades (distància, empresa i municipi de d'origen, etc.) |
| - Recorregut | Cal especificar les principals ciutats per on passa el mitjà de transport. Aquest ha de permetre fer una idea del circuit que es segueix per a fer el transport. Un exemple seria: Extremadura - Madrid - Saragossa - Girona. No és imprescindible més detall del recorregut, però com més exhaustiu sigui, més qualitat tindrà la dada i els resultats seran millors. |
| - Total km | Distància total en kilòmetres que realitza el vehicle des de l'origen fins el destí. S'ha d'indicar si el vehicle posteriorment torna buit o si transporta altres productes. |
| - Pes vehicle<br>- Capacitat vehicle<br>- Vida útil (anys) | El pes del vehicle, la capacitat i la vida útil és informació clau per a conèixer bé les condicions en que es produeixen els transports.<br>La vida útil fa referència a la quantitat d'anys que aquella màquina (o vehicle) es podrà utilitzar abans de que deixi de ser operativa . Aquesta dada és clau per assignar els impactes associats a màquines, aparells, calderes, camions, etc. |
| - Quantitat suro | Aquest paràmetre de referència fa més flexible el qüestionari ja que cada empresa pot expressar-ho de la manera que li sigui més fàcil. La quantitat de suro es pot expressar en les unitats que més s'escaiguin per a cada operació (kg, t, unitats en taps, etc.). Les unitats han d'estar sempre molt clares i tots els fluxos afegits a aquella taula hauran d'estar introduïts en base a aquest flux de referència. |
| - Quant. combustible i/o energia | La quantitat de combustible i/o energia es pot expressar en les unitats que més convingui (l o kg de combustible, kWh, MJ, etc.). Aquest apartat també és flexible per tal de poder-lo adaptar a cada operació. |
| - Màquines i/o aparells / Manual | Considerarem màquines qualsevol Alguns exemples de màquines són: calderes, tancs de bullida, màquines de picat de taps o de disc, màquines d'esmerilat, tractors, camions, toros, elevadors, muntacàrregues, traspalets mecànics, cintes transportadores, i cadascuna de les màquines de producció (triatge, picat, esmerilat, ...), etc.<br>Considerarem aparells aquells instruments i eines que no tenen un consum energètic propi: traspalets manuals, gàbies, sils, mescladors de cola, destrals, carretons, etc.<br>Per a cada màquina o aparell que s'utilitzi en una *manipulació;* s'haurà d'introduir i omplir una nova fila al qüestionari. De manera que tota la maquinària/aparells o manipulació manuals quedin reflectides en el qüestionari i per tant es tingui coneixement de tot el que passa durant el cicle de vida del producte.<br>Si hi ha màquines o aparells que s'usen en paral·lel; també s'hauran d'introduir totes i cadascuna d'elles, tot indicant-ne el percentatge d'ús al llarg de l'any de cadascuna d'elles, i les raons (perquè produeix més per hora, perquè és més moderna, perquè gasta menys, perquè va millor, perquè és per fer una *manipulació* poc habitual, etc.).<br>També és important les operacions manuals que es pugui realitzar perquè estiguin considerades en l'avaluació ambiental, ja que moltes vegades es produeix un impacte encara que aparentment no ho sembli. Per exemple en els processos de triatge de taps manuals es produeix un rebuig de material que no fa una màquina sinó una persona. |
| - Rebuig | El rebuig és el suro que surt del sistema i que no s'utilitzarà per a realitzar aquell producte. S'haurà d'especificar a *observacions* que se'n fa d'aquest residu o subproducte per tal de tenir-ho en compte alhora d'assignar els impactes ambientals. |
| - Productes | Com a productes es consideren tots els materials de cada operació: detergents, disolvents, parafines, silicones, bosses de polietilè, etc.<br>Cal considerar tots els productes que s'utilitzin en cada operació. Si per una operació s'utilitza en ocasions un producte i en d'altres un altre, caldrà especificar-ho a observacions així com assignar quin percentatge de taps es fa amb un i quin amb l'altre. Es podrà expressar amb les unitats que més convingui (l, kg, ampolla, dosi, etc.) però sempre en referencia a la quantitat de suro. |
| - Aigua | S'haurà d'especificar la quantitat d'aigua que s'utilitzi en la operació en litres o metres cúbics. En casos en que s'utilitzi aigua en el procés i no hi hagi un espai determinat per a aquesta matèria, es podrà posar com a productes. |
| - Temps de realització | El temps de realització és un paràmetre important ; especialment si hi ha màquina involucrades..<br>Determinar el temps de realització d'una operació pot semblar molt complicat, però sovint és més fàcil del que sembla: per exemple si se sap que per descarregar un camió que porta 2 t de suro es tarda 2 hores, ja tenim el valor que busquem. |

All the questionnaires were designed to be very flexible because it had been observed that each company had its own way of collecting and organizing data. This flexibility had advantages and drawbacks. The main advantage was that the questionnaire was very user-friendly, in that everyone could supply the requested information in their own way. On the other hand, flexibility meant subsequently working very hard to homogenize the data from every questionnaire in order to have the same units and a common reference for all the experimental samples studied. However, thanks to having different samples, some mistakes were detected and the quality of the final inventory was improved notably.

# AI.1. Cork oak forest management questionnaire

Following the cork oak forest management questionnaire is presented.

### Fitxa 0: Dades bàsiques finca forestal

| **01 - Dades generals de la finca** | |
|---|---|
| **Nom de l'empresa/finca:** | **Telèfon de contacte (Fax):** |
| **Adreça:** | **Correu electrònic:** |
| **Municipi:** | **Web:** |
| **Codi postal:** | **Persona de contacte:** |

| **02 – Característiques generals de l'explotació.** | | | | | | |
|---|---|---|---|---|---|---|
| **Superfície total (Ha):** | | | **Coordenades UTM (X,Y):** | | | |
| **Rang altitud sobre nivell del mar (m):** | | | **Temperatura anual mitjana (ºC):** | | | |
| **Pluviometria anual mitjana (mm):** | | | | | | |
| **Textura del sòl** | **% sorres** | | **% llims** | | **% argiles** | |
| | **pH** | | **% mat. orgànica** | | **% humitat** | |
| **Observacions:** | | | | | | |

| **03 - Dades laborals** | |
|---|---|
| **Número de treballadors/es:** | |
| **Períodes laborals (1):** | **Total dies treballats a l'any (1):** |
| Períodes extracció del suro: | Total dies extracció del suro: |
| Períodes extracció fusta: | Total dies extracció fusta: |
| Períodes extracció biomassa: | Total dies extracció biomassa: |
| Períodes extracció altres productes del bosc (2): | Total dies extracció altres productes del bosc (2): |
| **Horari laboral:** | **Períodes de vacances:** |
| **Observacions:**<br><br>(1) Per cada producte extret s'ha de definir una período de temps i el total de dies anuals treballats.<br>(2) Per cada producte extret del bosc afegir una nova fila. | |

| **04 – Dades de producció anual** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Producte** | **2005** | | **2006** | | **2007** | | **2008** | |
| | **Valor** | **Unitats** | **Valor** | **Unitats** | **Valor** | **Unitats** | **Valor** | **Unitats** |
| **Pelagrí i trossos** | | | | | | | | |
| **Suro de 2a pelada** | | | | | | | | |
| **Suro de reproducció** | | | | | | | | |
| **Fusta** | | | | | | | | |
| **Altres** | | | | | | | | |
| **Observacions:**<br><br>(1) Per cada producte s'ha d'inserir una nova fila | | | | | | | | |

| 05 – Característiques generals de la finca | | | | |
|---|---|---|---|---|
| **ALZINES SURERES** | | | | |
| **Nom – estadi evolutiu** | **Edat (anys)** | **Num. peus** | **Quantitat de suro (t)** | **Quantitat de fusta extreta (t)** |
| Creixement | >30 | | | |
| Pelagrí | 30-43 | | | |
| Matxot | 43-56 | | | |
| 3ª Pelada | 56- 69 | | | |
| 4ª Pelada | 69-82 | | | |
| 5ª Pelada | 82-95 | | | |
| 6ª Pelada | 95-108 | | | |
| 7ª Pelada | 108-121 | | | |
| 8ª Pelada | 121-134 | | | |
| 9ª Pelada | 134-147 | | | |
| 10ª Pelada | 147-160 | | | |
| 11ª Pelada | 160-173 | | | |
| 12ª Pelada | 173-186 | | | |
| 13ª Pelada | 186-199 | | | |
| 14ª Pelada | 199-212 | | | |
| 15ª Pelada | 212-225 | | | |
| 16ª Pelada | 225-238 | | | |
| 17ª Pelada | 238-251 | | | |
| Improductius | >250 | | | |
| **ALTRES ESPÈCIES ARBÒRIES (1)** | | | | |
| **Nom – estadi evolutiu** | **Edat (anys)** | **Num. peus** | **Quantitat de fusta extreta (t)** | **% sobre el total de la finca** |
| Pins | | | | |
| Alzines | | | | |
| Roures | | | | |
| Eucaliptus | | | | |
| Altres | | | | |
| **ALTRES ESPÈCIES ARBUSTIVES (2)** | | | | |
| **Nom – estadi evolutiu** | **Num. peus** | **Quantitat de biomassa (t)** | **% sobre el total de la finca** | |
| Arboç | | | | |
| Boix | | | | |
| Bruc | | | | |
| Estepa | | | | |
| Marfull | | | | |
| Altres | | | | |

**Observacions:**

(1) Per cada espècie arbòria s'ha d'introduir una nova línia, i si es tenen dades diferenciades per edats també. Només incloure espècies representatives i amb més d'1% de presència en el global de la finca.
(2) Per cada espècie arbustiva s'ha d'introduir una nova línia. Només incloure espècies representatives i amb més d'1% de presència en el global de la finca.

| 07 – Informacions vàries de la finca |
|---|
| **Teniu implantat un Pla tècnic de gestió i millora ambiental?** *Sí / No.* |
| *En cas afirmatiu adjuntar-lo.* |
| **Llicència municipal d'activitats:** *Sí / No / En tràmit* |
| **Inscripció en el Registre General de Gestors de Residus:** *Sí / No / En tràmit / No s'escau* |
| **Declaració anual de residus industrials:** *Sí / No / En tràmit / No s'escau* |
| **Fitxes d'acceptació i fulls de seguiment de residus:** *Sí / No / En tràmit / No s'escau* |
| **Registre documental de producció de residus (article 5.2 del Decret 93/1999 de procediments de gestió de residus):** *Sí / No / En tràmit / No s'escau* |
| **Auditories fetes per companyies d'assegurances i/o altres (1):** *Sí / No / En tràmit / No s'escau* |

**Observacions:**

(1) Qualsevol document que es consideri interessant per a tenir en compte, es podrà adjuntar.

# Fitxa A: Extracció del suro

| A1 – Desplaçament dels treballadors fins els punts d'extracció | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Treballadors per vehicle* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | |
| | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi / ** Es pot expressar com més convingui: hores de treballador per tona de suro, hores de treball per ha, etc.

| A2 – Extracció del suro | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Treballadors per vehicle* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| *Pelagrí/Fragments* | | | | | | | | |
| *Suro 2a pelada* | | | | | | | | |
| *Reproducció* | | | | | | | | |
| | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi / ** Es pot expressar com més convingui: hores de treballador per tona de suro, hores de treball per ha, etc.

| A3 – Desplaçament del suro des del peu de l'arbre fins a peu del camí | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Tipus de suro* | *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| *Pelagrí/Fragments* | | | | | | | | |
| *Suro 2a pelada* | | | | | | | | |
| *Reproducció* | | | | | | | | |
| | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi / ** Es pot expressar com més convingui: hores de treballador per tona de suro, hores de treball per ha, etc.

| A4 – Desplaçament del suro des del peu del camí fins a punt de reunió | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Tipus de suro* | *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| *Pelagrí/Fragments* | | | | | | | | |
| *Suro 2a pelada* | | | | | | | | |
| *Reproducció* | | | | | | | | |
| | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi / ** Es pot expressar com més convingui: hores de treballador per tona de suro, hores de treball per ha, etc.

| A5 – Aplicació de fungicida i colorant o altres productes als arbres* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual*** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització**** | | *Consum de combustible /energia* | | *Consum de productes* | |
| | | | | *(1)* | *(1)* | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Per cada producte que s'utilitzi cal afegir una nova fila (cal també adjuntar-ne la seva fitxa de seguretat o composició) / **Cal omplir una fila per a cada màquina que s'utilitzi / *** Es pot expressar com més convingui: hores de treballador per tona de suro, hores de treball per ha, etc.

| A6 – Classificació i apilament de les planxes de suro extretes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Tipus de suro* | *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| *Pelagrí/Fragments* | | | | | | | | |
| *Suro 2a pelada* | | | | | | | | |
| *Reproducció* | | | | | | | | |
| | | | | | | | | |
| **Observacions:** | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi / ** Es pot expressar com més convingui: hores de treballador per tona de suro, hores de treball per ha, etc. | | | | | | | | |

| A7 – Altres possibles operacions (homogeneïtzació de planxes, retallat de planxes, etc.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Tipus de suro* | *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| *Pelagrí/Fragments* | | | | | | | | |
| *Suro 2a pelada* | | | | | | | | |
| *Reproducció* | | | | | | | | |
| | | | | | | | | |
| **Observacions:** | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi / ** Es pot expressar com més convingui: hores de treballador per tona de suro, hores de treball per ha, etc. | | | | | | | | |

| A8 – Càrrega dels vehicles per transport a planta preparadora | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Tipus de suro* | *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| *Pelagrí/Fragments* | | | | | | | | |
| *Suro 2a pelada* | | | | | | | | |
| *Reproducció* | | | | | | | | |
| | | | | | | | | |
| **Observacions:** | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi / ** Es pot expressar com més convingui: hores de treballador per tona de suro, hores de treball per ha, etc. | | | | | | | | |

## Fitxa B: Extracció d'altres productes en boscos d'alzina surera (any n)

| B1 – Desplaçament dels treballadors fins els punts d'extracció de productes (mel, pinyes, biomassa, fusta, llenya, etc.)* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Treballadors per vehicle* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| ** | | | | | | | | |
| | | | | | | | | |
| **Observacions:** | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una taula igual per a cada producte que s'extregui | | | | | | | | |

| B2 – Extracció dels productes (mel, pinyes, biomassa, fusta, llenya, etc.)* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual*** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització**** | | *Consum de combustible /energia* | | *Quantitat de producte extret* | |
| | | | | *(1)* | *(1)* | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una taula igual per a cada producte que s'extregui | | | | | | | | | |

## Fitxa C: Gestió forestal de boscos d'alzina surera: Ratllat (any n+3)

| C1 – Desplaçament dels treballadors fins els punts de gestió per executar el ratllat | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Treballadors per vehicle* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | | |
| | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats

| C2 – Ratllat dels arbres | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Màquina o Manual*** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització**** | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | |
| | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats

## Fitxa D: Gestió forestal de boscos d'alzina surera: Ratllat (any n+6 i n+12)

| D1 – Desplaçament dels treballadors fins els punts de neteja de camins 1 (n+6) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Treballadors per vehicle* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | | |
| | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per cada operació i màquina que s'usi. / ** expressar com més convingui: hores per ha, hores per t, etc.

| D2 – Neteja de camins 1 (n+6) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització*** | | *Consum de combustible /energia* | | *Quantitat de biomassa extreta**** | |
| | | | | *(1)* | *(1)* | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per cada operació i màquina que s'usi. / ** expressar com més convingui: hores per ha, hores per t, etc. / *** Caldrà detallar el tipus de biomassa i la gestió que se'n faci.

| D3 – Desplaçament dels treballadors fins els punts de neteja de camins 2 (n+13) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Treballadors per vehicle* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | | |
| | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per cada operació i màquina que s'usi. / ** expressar com més convingui: hores per ha, hores per t, etc.

| D4 – Neteja de camins 2 (n+13) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització*** | | *Consum de combustible /energia* | | *Quantitat de biomassa extreta**** | |
| | | | | *(1)* | *(1)* | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per cada operació i màquina que s'usi. / ** expressar com més convingui: hores per ha, hores per t, etc. / *** Caldrà detallar el tipus de biomassa i la gestió que se'n faci.

| D5 – Desplaçament per a altres operacions de neteja o manteniment de bosc | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Treballadors per vehicle* | *Temps de realització*** | | *Consum de combustible /energia* | |
| | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | | |
| | | | | | | | | |
| **Observacions:** | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per cada operació i màquina que s'usi. / ** expressar com més convingui: hores per ha, hores per t, etc. | | | | | | | | |

| D6 – Altres operacions de neteja o manteniment de bosc | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual** | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització*** | | *Consum de combustible /energia* | | *Quantitat de biomassa extreta**** | |
| | | | | *(1)* | *(1)* | *(1)* | *(2)* | *(1)* | *(2)* |
| | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per cada operació i màquina que s'usi. / ** expressar com més convingui: hores per ha, hores per t, etc. / *** Caldrà detallar el tipus de biomassa i la gestió que se'n faci. | | | | | | | | | |

## Fitxa E: Transport de Finca a Preparadora

| E1 - Recorreguts vehicles (camions, furgonetes, cotxes, etc.) – SURO DE REPRODUCCIÓ | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Finca d'origen* | *Municipi origen* | *Empresa preparadora* | *Municipi preparadora* | *Recorregut* | *Total Km*** | *Pes vehicle (t)* | *Capacitat vehicle (m³)* | *Vida útil (anys)* | *Quantitat suro* | | *Consum combustible* | |
| | | | | | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Observacions:** | | | | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada destinació / ** S'ha d'indicar si el vehicle realitza el viatge de tornada amb d'altres productes o si torna buit. | | | | | | | | | | | | |

| E2 - Operacions de càrrega i descàrrega dels vehicles – SURO DE REPRODUCCIÓ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc. | | | | | | | | | |

| E3 - Recorreguts vehicles (camions, furgonetes, cotxes, etc.) – SURO PER GRANULAR | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Finca d'origen* | *Municipi origen* | *Empresa preparadora* | *Municipi preparadora* | *Recorregut* | *Total Km*** | *Pes vehicle (t)* | *Capacitat vehicle (m³)* | *Vida útil (anys)* | *Quantitat suro* | | *Consum combustible* | |
| | | | | | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Observacions:** | | | | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada destinació / ** S'ha d'indicar si el vehicle realitza el viatge de tornada amb d'altres productes o si torna buit. | | | | | | | | | | | | |

| E4 - Operacions de càrrega i descàrrega dels vehicles – SURO PER GRANULAR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc. | | | | | | | | | |

| E5 - Recorreguts vehicles (camions, furgonetes, cotxes, etc.) – ALTRES PRODCUTES NO SURERS* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Finca d'origen* | *Municipi origen* | *Empresa preparadora* | *Municipi preparadora* | *Recorregut* | *Total Km**** | *Pes vehicle (t)* | *Capacitat vehicle (m³)* | *Vida útil (anys)* | *Quantitat suro* | | *Consum combustible* | |
| | | | | | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| ** | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Observacions:** | | | | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Per cada producte cal inserir una nova taula / ** Cal omplir una fila per a cada destinació / *** S'ha d'indicar si el vehicle realitza el viatge de tornada amb d'altres productes o si torna buit. | | | | | | | | | | | | |

| E6 - Operacions de càrrega i descàrrega dels vehicles – ALTRES PRODUCTES NO SURERS* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| ** | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>*Per cada producte cal inserir una nova taula / ** Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc. | | | | | | | | | |

# AI.2. Natural cork stopper questionnaire

Following the natural cork stopper questionnaire is presented.

## Fitxa 0: Dades bàsiques industria tap de suro natural

| 01 - Dades generals de planta | |
|---|---|
| **Nom de l'empresa:** | **Telèfon de contacte (Fax):** |
| **Adreça:** | **Correu electrònic:** |
| **Municipi:** | **Web:** |
| **Codi postal:** | **Persona de contacte:** |

| 02 - Dades de superfície | | |
|---|---|---|
| **Superfície total ($m^2$):** | | |
| *Superfície fàbrica ($m^2$):* | *Superfície oficines (m2):* | *Superfície patis (m2):* |

| 03 - Dades laborals | |
|---|---|
| **Número de treballadors/es:** | **Torns:** |
| **Dies de treball setmanal:** | **Períodes de vacances:** |
| **Horari laboral:** | **Parades regulars de la producció:** |

| 04 - Característiques matèries prima (suro) | | | | | |
|---|---|---|---|---|---|
| **Matèria prima** | **Pes mitjà (kg)** | **Amplada (cm)** | **Llargada (cm)** | **Alçada (cm)** | **Quantitat (unitats)** |
| *Panna de bosc* | | | | | |
| *Panna bullida* | | | | | |
| *Fardo de bosc* | | | | | |
| *Fardo bullit* | | | | | |
| **Observacions:** | | | | | |

| 05 - Característiques de taps semielaborats[18] | | | | | | |
|---|---|---|---|---|---|---|
| | **Diàmetre (mm)** | **Llargada (mm)** | **Pes (g)** | **Densitat (g/cm³)** | **Quantitat (núm. taps)** | **(%) Producció** |
| *Tap semielaborat (1)* | | | | | | |
| *Tap semielaborat (2)* | | | | | | |
| **Observacions:** | | | | | | |

| 06 - Producció de taps de suro natural el darrer any i característiques | | | | | | |
|---|---|---|---|---|---|---|
| | **Diàmetre (mm)** | **Llargada (mm)** | **Pes (g)** | **Densitat (g/cm³)** | **Quantitat (núm. taps)** | **(%) Producció** |
| *Natural* | *24* | *38* | | | | |
| *Natural* | *24* | *44* | | | | |
| *Natural* | *24* | *49* | | | | |
| *Natural* | *24* | *54* | | | | |
| *Colmatat* | *24* | *38* | | | | |
| *Colmatat* | *24* | *44* | | | | |
| *Colmatat* | *24* | *49* | | | | |
| *Colmatat* | *24* | *54* | | | | |
| *Totals* | - | - | | | | |
| **Observacions:** | | | | | | |

| 07 – Informacions vàries de la indústria |
|---|
| **Potència contractada kW:** |
| **Potència autoritzada kW:** |
| **Teniu implantat un sistema de gestió o gestió mediambiental?** *Sí / No.* |
| *En cas afirmatiu: EMAS / ISO 9001 / ISO 14001* |
| **Llicència municipal d'activitats:** *Sí / No / En tràmit* |
| **Autorització/Llicència ambiental (Llei 3/98, de 27 de febrer):** *Sí / No / En tràmit* |
| **Autorització i/o permís d'abocament:** *Sí / No / En tràmit / No s'escau* |
| **Autorització de captació d'aigües:** *Sí / No / En tràmit / No s'escau* |
| **Autoritzacions de reaprofitament d'aigües residuals:** *Sí / No / En tràmit / No s'escau* |
| **Autorització per al tractament de residus en l'establiment mateix:** *Sí / No / En tràmit / No s'escau (Codi: .....................)* |
| **Inscripció en el registre de productors de residus industrials de Catalunya:** *Sí / No / En tràmit / No s'escau (Codi: .....)* |
| **Inscripció en el Registre General de Gestors de Residus:** *Sí / No / En tràmit / No s'escau* |
| **Declaració anual de residus industrials:** *Sí / No / En tràmit / No s'escau* |
| **Fitxes d'acceptació i fulls de seguiment de residus:** *Sí / No / En tràmit / No s'escau* |
| **Registre documental de producció de residus (article 5.2 del Decret 93/1999 de procediments de gestió de residus):** *Sí / No / En tràmit / No s'escau* |
| **Autorització de sistema de dipòsit, devolució i retorn d'envasos (disposició addicional 1a de la Llei 11/1997, d'envasos i residus d'envasos):** *Sí / No / En tràmit / No s'escau* |
| **Estudi de minimització de residus especials (Reial decret 952/1997, de 20 de juny (BOE núm. 160 de 5.7.1997), pel qual es modifica el Reglament per a l'execució de la Llei 20/1986 bàsica de residus tòxics i perillosos, aprovat pel Reial decret 833/1988):** *Sí / No / En tràmit / No s'escau* |
| **Plans graduals de reducció d'emissions a l'atmosfera:** *Sí / No / En tràmit / No s'escau* |
| **Declaració d'impacte ambiental:** *Sí / No / En tràmit / No s'escau* |
| **Declaració d'ús i contaminació de l'aigua (DUCA):** *Sí / No / En tràmit / No s'escau* |
| **Inscripció en el Registre d'Establiments Industrials de Catalunya (REIC):** *Sí / No / En tràmit / No s'escau* |
| **Auditories fetes per companyies d'assegurances i/o altres:** *Sí / No / En tràmit / No s'escau* |
| **Disposeu de vehicles propis de l'establiment?** *Sí / No* |
| **Disposeu de muntacàrregues i/o ascensors?** *Sí / No* |
| **Disposeu de sistema de fred i calor en producció***? Sí / No* |
| **Observacions:** |

[18] Hi ha empreses que no s'encarreguen de la producció completa sinó que compren taps prefabricats i llavors continuen el procés. A més, hi pot haver empreses que per demandes puntuals comprin taps semielaborats ocasionalment.

## Fitxa A: Transport de Finca a Preparadora

| A1 - Recorreguts vehicles (camions, furgonetes, cotxes, etc.) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Finca d'origen* | *Municipi origen* | *Empresa preparadora* | *Municipi preparadora* | *Recorregut* | *Total Km*** | *Pes vehicle (t)* | *Capacitat vehicle (m³)* | *Vida útil (anys)* | *Quantitat suro* | | *Consum combustible* | |
| | | | | | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | | |
| | | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada finca en la que es treballi. I també cal omplir diferents files si s'utilitzen diferents vehicles en una mateixa finca. / ** S'ha d'indicar si el vehicle realitza el viatge de tornada amb d'altres productes o si torna buit.

| A2 - Operacions de càrrega i descàrrega dels vehicles | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

## Fitxa B: Preparació de les planxes de suro

| B1 - Recepció del Suro per preparar: Operacions de càrrega, descàrrega i magatzem | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| B2 - Desplaçament planxes suro a bullir | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| B3 - 1a Bullida | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat d'aigua i altres matèries usades* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (caldera, grua per introduir les pannes, altres màquines) / ** Cal introduir una fila per cada matèria que s'utilitzi

| B4 - Desplaçament planxes suro a magatzem després 1a bullida | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| B5 - Estabilització després 1a Bullida i emmagatzematge | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat matèries usades* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (caldera, grua per introduir les pannes, altres màquines) / ** Cal introduir una fila per cada matèria que s'utilitzi.

| B6 - Desplaçament planxes suro a retallar | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| B7 - Retall i despuntat | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat matèries usades* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Les eines manuals no es tenen en compte. / ** Si no s'utilitza cap màquina caldrà omplir només les caselles corresponents al temps d'operació, la quantitat de suro que s'utilitza i la quantitat de rebuig.

| B8 - Desplaçament planxes suro a triatge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| B9 - Triatge de les planxes (electrònic i manual) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat matèries usades* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cadascuna de les màquines que s'utilitzi. / ** Pel triatge manual només cal omplir el temps d'operació, la quantitat de suro que entra i la quantitat de rebuig.

| B10 - Desplaçament de planxes triades i de rebuig | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| B11 - Premsat i enfardat | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat matèries usades* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | | | |
| | | | | | | | | | | | |
| **Observacions:** | | | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cadascuna de les màquines que s'utilitzi. / ** Per les accions manuals només cal omplir el temps d'operació, la quantitat de suro que entra i la quantitat de rebuig. | | | | | | | | | | | |

| B12 - Desplaçament i Emmagatzematge suro acabat de preparar | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc. | | | | | | | | | |

## Fitxa C: Transport Suro Preparat

| C1 - Recorreguts vehicles (camions, furgonetes, etc.) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Finca d'origen* | *Municipi origen* | *Empresa preparadora* | *Municipi preparadora* | *Recorregut* | *Total Km*** | *Pes vehicle (t)* | *Capacitat vehicle (m³)* | *Vida útil (anys)* | *Quantitat suro* | | *Consum combustible* | |
| | | | | | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Observacions:** | | | | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada proveïdor de suro preparat o per grups de proveïdors. / ** S'ha d'indicar si el vehicle realitza el viatge de tornada amb d'altres productes o si torna buit. | | | | | | | | | | | | |

| C2 - Operacions de càrrega i descàrrega dels vehicles | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc. | | | | | | | | | |

## Fitxa D: Fabricació del tap de suro

| D1 - Recepció del Suro Preparat i emmagatzematge (Operacions de Càrrega i Descàrrega) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc. | | | | | | | | | |

| D2 - Desplaçament planxes suro a 2a bullida | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc. /** En el cas de que es subcontracti caldrà omplir el Full "Annex" on hi ha una fitxa de transports entremitjos. | | | | | | | | | |

| D3 - 2a Bullida | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat d'aigua i altres matèries usades* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */**/*** | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (caldera, grua per introduir les pannes, altres màquines) / ** Cal introduir una fila per cada matèria que s'utilitzi. /*** En el cas de que es subcontracti, caldrà demanar aquestes dades a l'empresa subcontractada.

| D4 - Desplaçament planxes suro a Trau | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| D5 - Estabilització després de la 2a bullida | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat matèries usades* | | *Quantitat de suro rebutjat* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Sinó hi ha cap màquina en l'operació, només caldrà omplir la quantitat de suro tractada, el temps d'estabilització, i si s'aplica algun producte (ozó) per a mantenir les condicions, i si hi ha rebuig.

| D6 - Desplaçament planxes suro al llescat | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| D7 - Llescat de les planxes | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat rebuig* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cadascuna de les màquines que s'utilitza. / ** Si una de les màquines per a una mateixa funció s'utilitza majoritàriament s'ha d'indicar a observacions el percentatge de temps que representa cadascuna.

| D8 - Desplaçament llesques suro al picat | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| D9 - Picat del Tap | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat rebuig* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cadascuna de les màquines que s'utilitza. /** Si una de les màquines per a una mateixa funció s'utilitza majoritàriament s'ha d'indicar a observacions el percentatge de temps que representa cadascuna.

| D10 - Desplaçament taps a rectificació dimensional | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

| D11 - Rectificació Dimensional del tap | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat rebuig* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cadascuna de les màquines que s'utilitza. /** Si una de les màquines per a una mateixa funció s'utilitza majoritàriament s'ha d'indicar a observacions el percentatge de temps que representa cadascuna.

| D12 - Desplaçament i Emmagatzematge taps fabricats pendents de l'acabat | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

## Fitxa E: Transport a Acabat

| E1 - Recorreguts vehicles (camions, furgonetes, etc.) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Finca d'origen* | *Municipi origen* | *Empresa preparadora* | *Municipi preparadora* | *Recorregut* | *Total Km*** | *Pes vehicle (t)* | *Capacitat vehicle (m³)* | *Vida útil (anys)* | *Quantitat suro* | | *Consum combustible* | |
| | | | | | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada proveïdor de taps semielaborats. / ** S'ha d'indicar si el vehicle realitza el viatge de tornada amb d'altres productes o si torna buit.

| E2 - Operacions de càrrega i descàrrega dels vehicles | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

## Fitxa F: Acabat dels taps de suro

### F1 - Recepció dels taps fabricats (Operacions de Càrrega i Descàrrega)

| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

### F2 - Desplaçament dels taps fabricats a esbandir

| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

### F3 - Esbandit amb aigua

| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat matèries usades* | | *Quantitat d'aigua usada* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina involucrada en el procés. / ** En el cas de que es subcontracti, caldrà demanar aquestes dades a l'empresa subcontractada.

### F4 - Desplaçament dels taps esbandits a rentat

| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

### F5 - Rentat de taps

| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat matèries usades* | | *Quantitat d'aigua usada* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina involucrada en el procés. / ** Cal omplir una fila amb cada matèria que s'utilitzi (detergents, catalitzadors, etc.)

### F6 - Desplaçament dels taps rentats a secat

| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, silos, traspalets, etc.

| F7 - Secat dels taps | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat d'aigua i altres matèries usades* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina involucrada en el procés. Si n'hi ha més d'una per a una mateixa funció s'haurà d'especificar a observacions el percentatge d'ús de cadascuna.

| F8 - Desplaçament dels taps secats a igualar | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, silos, traspalets, etc.

| F9 - Igualat dels taps | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat d'aigua i altres matèries usades* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina involucrada en el procés. Si n'hi ha més d'una per a una mateixa funció s'haurà d'especificar a observacions el percentatge d'ús de cadascuna.

| F10 - Desplaçament dels taps igualats a Triatge de taps acabats | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, silos, traspalets, etc.

| F11 - Triatge de taps acabats (manual i electrònic) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat suro rebutjat (taps)* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina involucrada en el procés. Si n'hi ha més d'una per a una mateixa funció s'haurà d'especificar a observacions el percentatge d'ús de cadascuna.

| F12 - Desplaçament de taps triats i de rebuig | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, silos, traspalets, etc.

| F13 - Marcatge de taps | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat materials (tintes)* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | |
| | | | | | | | | | | | |
| **Observacions:** | | | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina involucrada en el procés. Si n'hi ha més d'una per a una mateixa funció s'haurà d'especificar a observacions el percentatge d'ús de cadascuna. | | | | | | | | | | | |

| F14 - Desplaçament de taps marcats a Tractament superficial | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, silos, traspalets, etc. | | | | | | | | | |

| F15 - Tractament superficial | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat materials (silicones, parafines, reactius)* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | |
| | | | | | | | | | | | |
| **Observacions:** | | | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina involucrada en el procés. Si n'hi ha més d'una per a una mateixa funció s'haurà d'especificar a observacions el percentatge d'ús de cadascuna. | | | | | | | | | | | |

| F16 - Desplaçament de taps a recompte | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, silos, traspalets, etc. | | | | | | | | | |

| F17 - Recompte | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, silos, traspalets, etc. | | | | | | | | | |

| F18 - Desplaçament de taps comptats a embalatge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| **Observacions:** | | | | | | | | | |
| (1) Valor / (2) Unitats<br>* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, silos, traspalets, etc. | | | | | | | | | |

| F19 - Embalatge | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | | *Quantitat materials embalatge* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina involucrada en el procés. Si n'hi ha més d'una per a una mateixa funció s'haurà d'especificar a observacions el percentatge d'ús de cadascuna.

| F20 - Emmagatzematge de taps acabats | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| */** | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, silos, traspalets, etc.

## Fitxa G: Transport del suro a Celler

| G1 - Recorreguts vehicles (camions, furgonetes, etc.) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Finca d'origen* | *Municipi origen* | *Empresa preparadora* | *Municipi preparadora* | *Recorregut* | *Total Km***| *Pes vehicle (t)* | *Capacitat vehicle (m³)* | *Vida útil (anys)* | *Quantitat suro* | | *Consum combustible* | |
| | | | | | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | | |
| | | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada proveïdor de taps semielaborats. / ** S'ha d'indicar si el vehicle realitza el viatge de tornada amb d'altres productes o si torna buit.

| G2 - Operacions de càrrega i descàrrega dels vehicles | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

## Fitxa H: Transport entremitjos

| H1 - Recorreguts vehicles (camions, furgonetes, etc.) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Finca d'origen* | *Municipi origen* | *Empresa preparadora* | *Municipi preparadora* | *Recorregut* | *Total Km*** | *Pes vehicle (t)* | *Capacitat vehicle (m³)* | *Vida útil (anys)* | *Quantitat suro* | | *Consum combustible* | |
| | | | | | | | | | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | | | | |
| | | | | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada proveïdor de taps semielaborats. / ** S'ha d'indicar si el vehicle realitza el viatge de tornada amb d'altres productes o si torna buit.

| H2 - Operacions de càrrega i descàrrega dels vehicles | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Màquina o Manual* | *Pes màquina (t)* | *Vida útil (anys)* | *Potència màquina (kW)* | *Temps de realització* | | *Quantitat de suro* | | *Consum de combustible /energia* | |
| | | | | *(1)* | *(2)* | *(1)* | *(2)* | *(1)* | *(2)* |
| * | | | | | | | | | |
| | | | | | | | | | |

**Observacions:**

(1) Valor / (2) Unitats
* Cal omplir una fila per a cada màquina que s'utilitzi (elevadors, toros, muntacàrregues, cintes transportadores, sils, traspalets, etc.

## Fitxa I: Matèries auxiliars de la producció de taps naturals

**I1 - Altres primeres matèries utilitzades en el procés productiu i no enumerades en les fitxes anteriors**

| Matèria prima (1) | | | | | Quantitat anual consumida | Procés en el que s'usa | Tipus emmagatz. (5) | Tipus de recipient i capacitat (6) | Capacitat cubetes de retenció (si s'escau) | Caract. emmagatz. (7) | Quantitat màxima emmagatz. (t) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nom genèric | Nom químic (si s'escau) | Núm. CAS o CEE (2) | Frase risc associada (3) | Codi CCPA-96 (4) | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

**Observacions:**

(1) No obvieu cap matèria o substància que, tot i utilitzant-se en baixa quantitat, per les seves característiques de toxicitat, persistència o bioacumulació, sigui mediambientalment significativa.
(2) El núm. CAS (Chemical Abstract) o el núm. CEE (Reial decret 363/1995, de 10 de març, (BOE núm. 133 de 5 de juny de 1995). Només en el cas que la matèria primera, per les seves característiques; de toxicitat, persistència o bioacumulació, sigui mediambientalment significativa (aquestes dades es troben en les fitxes de seguretat dels productes).
(3) Frase de risc (R40, R45, R46, R49, R60, R61) en cas que l'activitat estigui afectada per la Directiva 13/99 de compostos orgànics volàtils
(4) Codificació segons el CCPA-96 (taula de classificació catalana de productes per activitats, segons el Decret 131/1999, de 4 de maig, pel qual s'aprova la classificació catalana de productes per activitats CCPA-96).
(5) Indiqueu si disposeu de magatzem específic; cal indicar també si es tracta de dipòsit aeri, dipòsit soterrat, bidons, sitja aèria, sitja soterrada, sacs, botelles i botellons, bombones, altres.
(6) Si es tracta d'un recipient de plàstic, acer, vidre … doble paret i la capacitat dels recipients.
(7) Indicar pressió i temperatura d'emmagatzematge, si s'escau.

**I2 - Altres substàncies i matèries auxiliars (catalitzadors, terres de filtració, filtres, pintures, olis, reactius per a laboratori, productes de neteja, productes de jardineria, etc.) i no enumerades en les fitxes anteriors**

| Substància producte auxiliar (1) | | | Ús/procés en el qual s'utilitza | Quantitat màxima emmagatzemada (3) | Quantitat màxima consumida per any (4) |
|---|---|---|---|---|---|
| Nom genèric | Frase de risc associada (2) | Nom químic (si s'escau) | | | |
| | | | | | |
| | | | | | |

**Observacions:**

(1) No obvieu cap matèria o substància que, tot i utilitzant-se en baixa quantitat, per les seves característiques de toxicitat, persistència o bioacumulació, sigui mediambientalment significativa.
(2) Frase de risc (R40, R45, R46, R49, R60, R61) en cas que l'activitat estigui afectada per la Directiva 13/99 de compostos orgànics volàtils.
(3) Indiqueu el tipus d'envàs en què s'emmagatzema, capacitat de l'envàs i nombre d'envasos.
(4) Atesa la variabilitat, podeu donar una dada aproximada i cal indicar-ne les unitats.

## Fitxa J: Energia

**J1 - Tipus de fonts energètiques utilitzades i consum**

| | |
|---|---|
| **Elèctrica procedent de fonts externes:** *Sí / No* | **Potencia nominal total (kW):** |
| **Ús de combustibles:** *Sí / No* | **En cas afirmatiu, indiqueu quins:** |

| Combustible (1) | Tipus d'emmagatze- matge (2) | Tipus de recipient i capacitat (3) | Condicions d'emmagatzematge (4) | Quantitat màxima consumida/any (tones) |
|---|---|---|---|---|
| | | | | |
| | | | | |

**Observacions:**

(1) Indiqueu tipus de combustible utilitzat: lignit; hulla; antracita; biomassa; restes vegetals; carbó vegetal; coc; fuel BIA; fuel 1; fuel 2; gasoil; gasos liquats del petroli; gas natural; gasos manufacturats (acetilè i nitrogen). En cas de tractar-se d'altres combustibles, cal indicar-ne el tipus i en el cas que es tracti de residus combustibles cal indicar, a més del tipus de residu utilitzat com a combustible, la seva classificació segons el Catàleg de Residus de Catalunya (CRC).
(2) Indiqueu si disposeu de magatzem específic; cal indicar també si es tracta de dipòsit aeri, dipòsit soterrat, bidons, sitja aèria, sitja soterrada, sacs, botelles, botellons, altres.
(3) Si es tracta d'un recipient de plàstic, acer, vidre … doble paret i la capacitat del recipient.
(4) Indiqueu la pressió i temperatura d'emmagatzematge, si s'escau.

**J2 – Energies renovables**

| | |
|---|---|
| **Disposa d'energies renovables:** *Sí / No* | **En cas afirmatiu, indiqueu tipus: solar / eòlica / altres** |

**Observacions:**

**J3 - Bateries**

| | |
|---|---|
| **Utilitzeu bateries:** *Sí / No* | **En cas afirmatiu, indiqueu tipus: alcalines / plom / altres** |
| **Hi ha ventilació adequada a la sala d'ubicació de bateries:** *Sí / No* | **Existeix ventilació adequada zona de càrrega de bateries?** *Sí / No* |

**Observacions:**

| J4 – Instal·lacions industrials de combustió (convencionals) |
|---|
| **Disposeu d'instal·lacions industrials de combustió per portar a terme l'/les activitat/s del centre?** *Sí / No* |
| *En cas afirmatiu, indiqueu per a cada una de les instal·lacions de combustió les dades següents:* |

| Instal·lació combustió | Núm. llibre registre emissions | Potència nominal (1) | Potència condicions normals de treball (1) | Poder calorífic (2) | | Tipus de caldera (3) | Tipus de combustib. (4) | Consum mitjà Horari (5) | Consum màxim (5) | | Temps de funcion. (6) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Inf. | Sup. | | | | Horari | anual | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

| |
|---|
| **Hi ha cap sistema per prevenir i/o corregir l'emissió de contaminants atmosfèrics?** *Sí / No* |
| *En cas afirmatiu, indiqueu tipus i rendiment:* |
| **Observacions:** |

(1) Indiqueu les unitats en kW o Mw tèrmics.
(2) Indiqueu les unitats en kcal/kg.
(3) Indiqueu tipus de caldera: vapor, aigua calenta, caldera mixta, caldera d'oli tèrmic.
(4) Lignit; hulla; antracita; biomassa; restes vegetals; carbó vegetal; coc; fuel BIA; fuel 1; fuel 2; gas-oil; gasos liquats del petroli; gas natural; gasos manufacturats (acetilè i nitrogen); residus i altres (especificant de quin es tracta)
(5) Kg o tones, per dia o per any.
(6) En h/dia i d/any; en cas de tractar-se d'una indústria tèrmica, indiqueu h/any i d/any.

# Fitxa K: Gestió d'aigües

| K1 - Abastament d'aigua |
|---|
| **Cabal total abastat (m3/any):** |
| **Procedència, consums i usos de l'aigua. Si es considera oportú, aporteu un diagrama de flux de producció d'aigües residuals per a cadascun del usos en què intervé, o si es considera oportú aporteu un esquema de fluxos (balanç d'aigua):** |

| Procedència de l'aigua (1) | Consum | | Usos |
|---|---|---|---|
| | m3/h | m3/any | |
| | | | |

**Observacions:**

(1) Pou, captació d'aigües superficials, xarxa pública, cisternes, recirculació interna, altres (indiqueu-la).

| K2 - Abocament d'aigües residuals | |
|---|---|
| **Nombre total de punts d'abocament:** | **Cabal total abocat (m3/any):** |
| **Cabal total abocat (m3/dia):** | **Cabal punta horari (m3/h):** |
| **Volum de recirculació total (m3/dia):** | **Percentatge % de recirculació:…………….** |

**Es fa segregació d'efluents:** *Sí / No / No s'escau*

| Tipus d'afluent | Segregació a planta | Tipus de segregació |
|---|---|---|
| *Aigües sanitàries* | *Sí / No / No s'escau* | |
| *Aigües de pluja* | *Sí / No / No s'escau* | |
| *Aigües pluvials potencialment contaminades* | *Sí / No / No s'escau* | |
| *Aigües de procés* | *Sí / No / No s'escau* | |
| *Aigües de refrigeració* | *Sí / No / No s'escau* | |

**Observacions:**

| K3 - Emissions d'aigües residuals: dades específiques per a cada punt d'abocament |
|---|
| **Identificació dels focus generadors d'aigües residuals, el seu origen i sistema de recollida, evacuació i punt d'abocament el qual haurà d'estar degudament identificat en el plànol de clavegueram a annexar** |

| Punt d'abocament (coordenades) | | Procés genera. (1) | Cabal | | | Tractament sí/no (2) | Cont. abocats (3) | Concentració del contaminant abocada | | Conc. contam. autori. | Càrrega total contam. abocat (kg/d) | Destí aboc. (4) | Medi recept. (5) | Qual. medi recept. (6) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UTM X | UTM Y | | Punta (m3/h ) | Màx. ($m^3$/dia) | Total ($m^3$/any) | | | Valor mínim | Valor màxim | | | | | |
| | | | | | | | | | | | | | | |

**Observacions:**

(1) Cal indicar tots els possibles tipus d'aigües residuals (sanitàries, refrigeració, procés, així com les possibles aigües pluvials contaminades …).
(2) En cas d'efectuar-se algun tipus de tractament, cal indicar-ne el tipus. (desconegut, desbast, homogeneïtzació, neutralització, pretractament complet, pretractament especial, desgreixament, decantació flotació, decantació precipitació, fisicoquímica d'una reacció, fisicoquímica amb més d'una reacció, fisicoquímica + flotació, fisicoquímica + biològica, fisicoquímica + recirculació, fisicoquímica + modificació procés, fisicoquímica + minimització, biològic llacunatge, biològica (fossa sèptica o assimilable), biològica llots activats, biològica filtre percolador, biològica anaeròbic, biològic + recirculació, biològic + modificació procés, biològic + minimització, biològica més fisicoquímica, centrífug, filtre-premsa, filtre-banda, assecatge, altres, oxidació, ozonització, evaporació, oxidació tèrmica, osmosi, filtració, intercanvi iònic, carbó actiu, recirculació, minimització, modificació procés productiu, cap.
(3) Contaminants que figuren en l'autorització d'abocament i altres de significatius mediambientalment recollits en el Reglament del domini públic hidràulic (RD 849/1986) i en especial els de les substàncies contaminants dels annexos al títol III, provinents d'aplicació de la Directiva 76/464/CEE del Consell, de 4 de maig de 1976 i derivades, així com els altres que s'escaiguin.
(4) Sense abocament, cisterna a tractador privat, connexió a sistema de sanejament, EDAR pública amb cisternes, llera indirectament (amb xarxa de clavegueram), llera directament, mar directament, abocament per infiltració o abocament, altres casos d'abocament.
(5) Especifiqueu la llera, EDAR, etc.
(6) Per a tots aquells contaminants de què disposi de dades l'Administració.

## Fitxa L: Gestió de residus

| L1 – Gestió de residus | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Residu (1)** | **Procés en el qual es genera** | **Producció (t/any)** | **Capacitat màxima emmagatzematge** | **Tipus emmagatzematge (2)** | **Temps màxim emmagatzematge** | **Gestió en origen (3)** | **Gestió externa (3)** |
| | | | | | | | |
| | | | | | | | |

**Observacions:**

(1) Descripció i codificació segons CRC (annex I, Catàleg de residus de Catalunya), o tipus de subproducte.
(2) Temporal/permanent en piles/basses sense preparar; temporal/permanent en piles/basses en lloc preparat; temporal/permanent en piles/basses en llocs coberts; temporal/permanent en piles/basses en llocs enterrats; embalatge de residus en contenidors o bidons a la intempèrie; embalatge de residus en contenidors o bidons en llocs preparats i embalatge de residus en contenidors o bidons en llocs tancats.
(3) En el cas d'efectuar-se algun tipus de tractament, indiqueu-ne el tipus. Vegeu taules de l'annex I. En el cas de gestionar-se com a subproducte, indiqueu-ho.