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PhD Thesis

Proposal for a LCA improvement roadmap in the Agri-food sector based on information exchange requirements and the enclosed data in recent LCAs works

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Abstract

Innovation is essential to promote human progress and to improve the humans' quality of life, but it should be done in a social and environmental context and in accordance with the principles of sustainable development. To achieve this challenge the environmental innovation guidelines should be taken into account. In this line, it is necessary to analyze the life cycle assessment (LCA) of any product, process or service and compute its environmental impacts.

Despite the rapid evolution of environmental methods and tools and the increase of sustainability studies in recent years, LCA remains an area that still has to face major development challenges. This thesis provides an analysis from a new perspective with the intention to serve as a support in the conceptual and empirical application of the LCA in the Agri-food sector. It consists of a qualitative analysis designed to know the type of relationship between the different actors involved and their information exchange needs. The case study made it possible to compare the differences between the academic and the industrial fields, as well as the differences between Spanish and Brazilian LCA experts. Through expert panels, 40 specialists were interviewed and were asked to made a survey to evaluate experts' relationships using the Social Network Analysis method (SNA). Moreover, the network flow of environmental information in Brazil and Spain was mapped.

A second quantitative study was carried out reviewing 70 scientific publications of LCA in the Agri-food sector according to a checklist based on the definition of 20 control variables. The objective was to evaluate the quantity and quality of the information enclosed in the different works. To do this, the entropy and diversity of information were calculated using the Shannon and the equitability indexes, using the number of inputs considered in each impact category. A threshold of minimum information is proposed, using percentiles 25 and 75 (Tukey values) of the calculated Shannon indexes from the papers sample.

Moreover, a cluster analysis was done using 10 out the 20 control variable to classify LCAs into clusters with similar levels of performance for the LCAs of the same group and different from the LCA belonging to the other groups. Based on the analysis of the centers of resulting group, the strengths and weaknesses of each group were identified.

Then, a roadmap or improvement plan was succinctly defined, pointing out the actions to be taken to improve the performance levels in each group in the short, medium and long term.

Finally, a set of actions to improve and facilitate the implementation of LCA in the Agri-food sector was defined as a kind of good practice manual. In sum, it could be concluded that this present thesis could serve to improve the LCA studies

performance levels for industry, and, at the same time, it could serve as a baseline with which to compare academic standards of a more academic works.

Resumen

La innovación es esencial para promover el progreso de la humanidad y la mejora de la calidad de vida, pero debe realizarse respetando un suelo social y un techo ambiental de acuerdo con los principios del desarrollo sostenible. Para intentar conseguirlo surge la innovación ambiental. En esa línea, resulta necesario analizar el ciclo de vida (ACV) de cualquier producto, proceso o servicio y computar sus impactos ambientales.

A pesar de la rápida evolución de los métodos y herramientas y del incremento de estudios en los últimos años, el ACV sigue siendo un área que se enfrenta a retos de desarrollo importantes. Esta tesis proporciona un análisis desde una perspectiva nueva con la intención de servir de apoyo en la aplicación conceptual y empírica del ACV en el sector agroalimentario. Consta de un análisis cualitativo destinado a conocer el tipo de relación entre los distintos actores involucrados y sus necesidades de intercambio de información. El caso de aplicación permite comparar las diferencias entre el mundo académico y el industrial, así como las diferencias entre expertos en ACV de España y Brasil. A través de paneles de expertos se entrevistó a 40 especialistas y con un cuestionario se evaluó la red de contactos usando el método de Análisis de Redes Sociales (SNA). Con todo se mapeó el flujo de información ambiental en Brasil y España.

En un segundo estudio cuantitativo se realizó una revisión crítica de 70 publicaciones científicas de ACV pertenecientes al sector agroalimentario, evaluando las mejores revistas y congresos de todo el mundo entre 2010 y 2016 a partir de la definición de 20 variables de control. El objetivo era evaluar la cantidad y calidad de la información contenida en los distintos trabajos. Para ello se calculó la entropía y diversidad de la información a través del Índice de Shannon y del cálculo de la heterogeneidad en lo refiere al número de inputs considerados en cada categoría de impacto. Tras los valores obtenidos se proponen unos umbrales de información mínima aconsejable usando como límites el valor de las bisagras de Tukey de la distribución de los 70 índices de Shannon calculados.

Por otra parte, a partir de 10 de las 20 variables de control se agruparon los distintos ACV analizados con objeto de clasificarlos en grupos con parecido nivel de desempeño para los ACV de un mismo grupo y distinto al de los ACV pertenecientes al resto de grupos. A partir del análisis del análisis de los centros de cada grupo, se identificó las fortalezas y debilidades de cada grupo, para más tarde definir de forma sucinta un mapa de ruta o plan de mejora apuntando las acciones a realizar para mejorar los niveles de desempeño en el corto, medio y largo plazo de cada grupo.

Finalmente, se definió a modo de un manual de buenas prácticas un conjunto de acciones a realizar para mejorar y facilitar la realización de ACV en el sector agroalimentario. Con todo. Se podría concluir que la tesis puede servir para mejorar los niveles de desempeño de la realización futura de estudios de ACV en el sector industrial, al tiempo que podría servir como línea de base con la que comparar los estándares de estudios de carácter más académico.

Resum

La innovació és essencial per a promoure el progrés de la humanitat i la millora de la qualitat de vida, però ha de realitzar-se respectant un sòl social i un sostre ambiental d'acord amb els principis del desenrotllament sostenible. Per a intentar aconseguir-ho sorgix la innovació ambiental. En eixa línia, resulta necessari analitzar el cicle de vida (ACV) de qualsevol producte, procés o servici i computar els seus impactes ambientals.

A pesar de la ràpida evolució dels mètodes i ferramentes i de l'increment d'estudis en els últims anys, l'ACV continua sent una àrea que s'enfronta a reptes de desenrotllament importants. Esta tesi proporciona una anàlisi des d'una perspectiva nova amb la intenció de servir de suport en l'aplicació conceptual i empírica de l'ACV en el sector agroalimentari. Consta d'una anàlisi qualitativa destinada a conèixer el tipus de relació entre els distints actors involucrats i les seues necessitats d'intercanvi d'informació. El cas d'aplicació permet comparar les diferències entre el món acadèmic i l'industrial, així com les diferències entre experts en ACV d'Espanya i Brasil. A través de panells d'experts es va entrevistar a 40 especialistes i amb un qüestionari es va avaluar la xarxa de contactes usant el mètode d'Anàlisi de Xarxes Socials (SNA). Amb tot es dissenyà el flux d'informació ambiental a Brasil i Espanya.

En un segon estudi quantitatiu es va realitzar una revisió crítica de 70 publicacions científiques d'ACV pertanyents al sector agroalimentari, avaluant les millors revistes i congressos de tot el món entre 2010 i 2016 a partir de la definició de 20 variables de control. L'objectiu era avaluar la quantitat i qualitat de la informació continguda en els distints treballs. Per a això es va calcular l'entropia i diversitat de la informació a través de l'Índex de Shannon i del càlcul de l'heterogeneïtat en el que es refereix al nombre d'inputs considerats en cada categoria d'impacte. Després dels valors obtinguts es proposen uns llindars d'informació mínima aconsellable usant com a límits el valor de les frontisses de Tukey de la distribució dels 70 índexs de Shannon calculats.

D'altra banda, a partir de 10 de les 20 variables de control es van agrupar els distints ACV analitzats a fi de classificar-los en grups amb paregut nivell d’excel·lència per als ACV d'un mateix grup i diferent del dels ACV pertanyents a la resta de grups. A partir de l'anàlisi de l'anàlisi dels centres de cada grup, es va identificar les fortaleses i debilitats de cada grup, per a més tard definir de forma succinta un mapa de ruta o pla de millora apuntant les accions a realitzar per a millorar els nivells d'exercici en el curt, mitjà i llarg termini de cada grup.

Finalment, es va definir a manera d'un manual de bones pràctiques un conjunt d'accions a realitzar per a millorar i facilitar la realització d'ACV en el sector agroalimentari. Amb tot, es podria concloure que la tesi pot servir per a millorar

els nivells d'exercici de la realització futura d'estudis d'ACV en el sector industrial, alhora que podria servir com a línia de base amb què comparar els estàndards d'estudis de caràcter més acadèmic.

Tree of Life carries the meaning that we are related with all, to our human family our animal family - our earth family and our beyond-the-earth family.

All of the Cosmos is interconnected - DNA and chemicals link us and it is in this sameness that we find compassion, tolerance and vision of future and it is in our differences that we should find wonder.

Here, the Tree of Life meaning tells us that although we are rooted in the Earth plane, we are reaching for the Spiritual Realms. Here we are each alone but thinking all together we are stronger...

The life cycle thinking carried out us to understand that we need integrate all life cycles in one, and this is our planet, not the unique but at this moment, our big cycle of life. Caring each other and making the good we will find the Peace and happiness.

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Nomenclature

Environmental impact	Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services (ISO 14041:1998).
LCA	A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle. (ISO 14040:1997).
Method	A way of working, in a predefined and systematic way, which facilitates the user's work towards a desired outcome.
Product	A system, object or service made to satisfy the needs of a customer (ENDREA 2001).
Product development	All activities in a company aiming at bringing a new product to the market. It normally involves design, marketing and manufacturing functions in the company (ENDREA 2001).
Requirement	A specific description of an attribute of something.
Tool	A means that, in a predefined and systematic way, facilitates the user's work towards a desired outcome.

Abbreviations

C	Carbon
CH4	Methane
CO2	Carbon dioxide
eq.	Equivalent
GWP	Global warm potential
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
LCA	Life Cycle Assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
kJ	Kilojoule
N2O	Nitrous oxide
NH3	Ammonia
NO3	Nitrate
PO4	Phosphate
UNEP	United Nations Environment Program
WBCSD	World Business Council for Sustainable Development
EPD	Environmental Product Declaration

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Chapter 1

Introduction

1 - Introduction

1.1 - Problem Description

An economic system based on maximum output, consumption and unlimited exploitation of resources which considers profit as the sole criterion for good economic progress is unsustainable. Planet Earth is generous but finite, so it cannot indefinitely supply the limited resources required by such exploitation. Therefore, it is necessary to advance towards the kind of development capable of improving living conditions and, at the same time, be able to withstand a rational exploitation of resources that respects the environment. This approach is the so-called sustainable development, which is a development that meets present needs without compromising the ability of future generations to meet their own needs.

To meet this challenge, a paradigm shift is needed that allows industries to innovate in a sustainable way. In this sense, environmental innovation is defined as the production, assimilation and exploitation of products, production processes, services or business and management methods, which aims to prevent or substantially reduce, throughout its life cycle, environmental risks, pollution and other negative impacts of resources use (Kemp & Foxon, 2007). To meet this challenge, an attitude change is needed, as well as the development of new technologies, environmental technologies or the so-called "clean tech", which is based on the application of environmental innovation concepts.

Both academia and industry need to develop appropriate evaluation methodologies and tools for the definition of these new environmental technologies, ensuring objectivity and reliability (Wheelwright & Clark, 1992). The use of tools to support analysis and decision-making is important in order to prioritize actions, as they allow modelling requirements to address complexity (Baumann, 2003). The Life Cycle Assessment (LCA) is one of the most powerful existing tools for environmental assessment. The LCA was created as a company-based tool in the 1960s, later becoming one of the most widely used and recommended methodologies to evaluate environmental impacts of products and services (McManus & Taylor, 2015).

The International Organization for Standardization (ISO) defined LCA in the standard series ISO 14040. The ISO 14040 standard (ISO, 2006) defines LCA as a compilation and evaluation of inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. This standard establishes that an LCA study has to be conducted in four main phases: (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment and (iv) interpretation (ISO 14040:2006).

The purpose of an LCA is to identify resource consumption and pollution production of products or services over their lifetime, from raw materials to their disposal, and anything in between (Guinée et al., 2002). The environmental impacts of these substances are evaluated as part of the Life Cycle Impact Assessment (LCIA).

Nowadays, this methodology allows comprehension of the correlations between different environmental aspects in a project and the effects beyond the project (McManus & Taylor, 2015). Moreover, LCA evolved from a tool that simply evaluates the impacts of production processes, services or products to a comprehensive scientific methodology that analyses processes and technology consequences for the market. Due to recent developments in the LCA area, it is currently possible to distinguish two different modeling approaches: attributional and consequential (Weidema et al., 2013). The attributional model provides information about the impacts generated by processes used to produce (and consume and dispose of) a product, but it does not consider indirect effects arising from changes in the output of a product (Brander, 2008). The aim of the consequential model is broader, exploring not only the impacts of production and use of a particular product considered in isolation, but also the wider changes to the overall system that may arise from using that product, and it often excludes the unchanged elements (Sanches et al., 2012).

The LCA is a very useful tool when identifying substances involved in production and consumption, but it has a few weaknesses: for instance, all the substances and their environmental impacts need to be evaluated in some way. This can be problematic, as the environmental impacts of a substance may not be accurately known (Pennington et al., 2004a and 2004b; Cornelissen & Hirs, 2002). Although the LCA is a powerful tool, its methods and solutions need some improvements in order to face specific geographical and political barriers in this field around the world (Björklund, 2002). Many studies results depend heavily on the initial decisions, such as modelling, functional unit definition, system boundaries, allocation procedures, etc. In case the corresponding stakeholder reads the full report, everything must be specified, which requires specific training. Moreover, the information about initial decisions needed to communicate or to compare the obtained data, but it is not always available, leading to misunderstandings or erroneous results interpretation (Guinée et al., 2011). Furthermore, the data collection process requires a considerable amount of time, since most of the required data has to be gathered outside the company.

Environmental impact calculation tools can be applied in many industrial sectors, but its application is especially important in the Agri-food sector. Agricultural production and the food processing industry generate significant environmental impacts which contribute to global warming, eutrophication and acidification (Pardo & Zufia, 2012; Ruviaro et al., 2014; Saarinen et al., 2012). Over the last decade, the LCA has been increasingly used for the qualification and quantification of these impacts, and also to meet the demand for optimization of food production (Notarnicola et al., 2012a). The data needed for an environmental analysis of food products, comprises not only the agricultural primary production, but also food processing (manufacturing), packaging, transport and waste management. Furthermore, a huge variability of agricultural practices exists within a country, being even larger on a global scale.

Scientific studies and publications generated in the last decades, have shown that most food chains are not sustainable because of the environmental impacts produced in different phases of their life cycle (Blengini & Busto, 2009; Friscknecht et al., 2007). Accordingly, the 2006–2020 Strategic Research Agenda of the European Technology Platform Food for Life has defined sustainable food production as the most important challenge the European food industry has to face.

Sustainability tools and LCA have been applied for more than 20 years to agricultural and food systems in order to identify sustainable food production and consumption methods, and as a mean for supporting environmental decision-making. Experts and academicians keep their focus on food LCA studies because of their complexity. Some methodological issues (e.g. functional unit definition, data collection difficulties, pesticides and their use, fertiliser dispersion models, impact categories, land and water use) are different from the typical ones arising from LCAs of industrial products (Notarnicola et al., 2014b). Moreover, according to Bastianoni et al. (2013) the existing libraries of life cycle inventory (LCI) and data on food are most often:

- Not transparent (friendly) enough;

- Incomplete: only few inventory flows are accounted for, which leads to an incomplete overview of the impacts of food products and thus, to misleading interpretations and conclusions;
- Inconsistent with each other, due to different approaches and assumptions (i.e. units);
- Outdated and consequently unreliable;
- Not geographically correlated (regionalized): country-specific data are not available or the region under study is not represented.

Considering the powerful LCA tool and its weaknesses and barriers when applied in a given industry, the main limitations are the lack of an environmental culture, difficulties to get information related to local databases, and the lack of professionals with the required training and skills.

In this scenario, it seems essential to find a way to overcome the aforementioned drawbacks in order to improve the quality of LCA applications and results. This could be especially important in the case of the Agri-food sector because of its international relevance and worldwide impact.

1.2 - Subject to be addressed

The present thesis aims to analyze data requirements and the information exchange among all involved agents when it comes to perform LCAs. Specifically, this research will study the data sharing requirements and the relationships between LCA stakeholders belonging to academy and industry in Brazil and Spain. The goal is to understand the environmental information exchange and to map it in both countries. Moreover, the present study attempts to evaluate the quantity and quality of the information enclosed in existing LCAs in the Agri-food industry. The goal is to measure such information in an objective way, in order to analyze the execution performance and reliability of LCA results major over the last seven years. As a whole, this thesis will propose a brief roadmap, a good practices manual, as well as a threshold of the amount of information needed to perform LCA with a minimum quality level in the Agri-food sector.

Chapter 2

Backgroud and literature review

2 - Background and literature review

2.1 - Introduction to LCA

Life Cycle Assessment is a method standardized by ISO 14040:2006 that is currently increasingly used for estimating the environmental impacts of some processes, services or a system. Nowadays, it is considered in many institutions as a core element of environmental policy. LCA can be defined as a “compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO 14040: 2006). LCA involves data collection and the quantitative evaluation of energy inputs and outputs, as well as material and waste flows related to a product or process over its entire life cycle so that the environmental impacts can be determined for the system boundary selected in the objective and scope stated for the analysis (Royal Society of Chemistry, 2012). Thus, the scope of the study must be firstly defined; resource stocks and inputs have to be quantified, their environmental impacts identified and assessed and finally, results must be interpreted (Royal Society of Chemistry, 2012). This tool provides the numerical values of material consumption, energy chain resource consumption and production of different categories and types of materials[1]. Therefore, the evaluation of resources depletion is included on LCA. LCA reveals differences between products, processes and includes services but, it does not assess process eficiency (Cornelissen, 1998).

2.1.1 - Environmental assessment of products and services

A) - Products:

The Life Cycle Assessment (LCA) can be applied to a facility in any industrial sector. This tool has been most often used in manufacturing facilities, especially those assembling final products, the civil industry and more recently it has been regarded with growing interest in the Agri-food industry.

Factors such as cost, manufacturability, and consumer acceptance limit the choice of materials, but do not determine their selection or the assembly techniques to be used. Thus, the initial designers planning role in the manufacturing industry is central and to select the best techniques and practices could be very important.

[1] For developments in LCA see Guineé et al., 2011.

An LCA must explicitly encompass the entire life cycle of a product. For a typical manufactured product, there are five life-cycle stages, as shown in Figure 1.

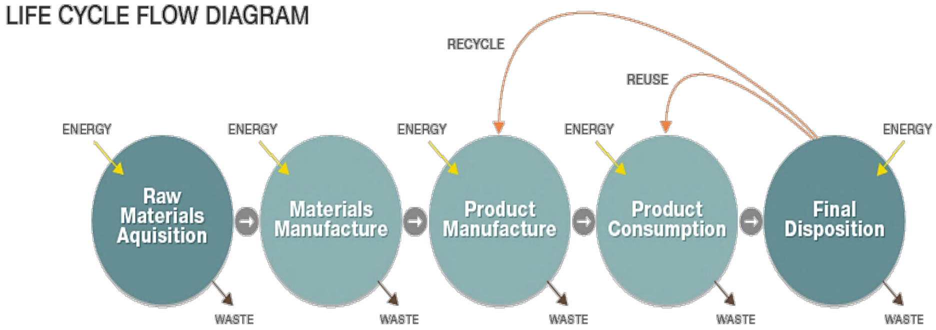


Figure 1: Product Life Cycle Diagram (by Elixir 2016).

Phase 1 - Raw material acquisition or Pre-manufacturing: This stage considers environmental impacts produced by raw materials extraction, transportation to processing facilities, their purification or separation by any process or operation, and their transportation to the manufacturing facilities.

Phase 2 - Materials manufacturing: considers the industrial processes involved in product creation.

Phase 3 - Product manufacturing and delivery: Involves packaging material manufacturing, its transport to the manufacturing facility, wastes generated during the packaging process, the logistic involved in the delivery of the finished and packaged product to the customer, (if applicable) product installation and it also considers some service processes' chain and also the product manufacturing are imputed in this phase.

Phase 4 - Product consumption: Involves impact calculation generated by consumables or maintenance materials (if they exist) that are used during the consumption stage. For some products, such as long life devices (e.g. vehicles), periodic maintenance is sufficiently important to be treated as a separate life stage coincident with the product use stage.

Phase 5 – Final disposition or End of life: When the product presents component degradation, it is no longer satisfactory because of scheduled obsolescence, due to a business strategy change or to personal decisions, it is refurbished, recycled, or simply discarded.

B) - Processes:

The issue of environmental assessment of processes is particularly important, since once developed they often remain in place for decades, and the creation of new products often depends on the continuing existence of those processes. Harmful environmental impacts of processes remain much longer than impacts produced by the design and manufacture of individual products.

As with products, the Life Cycle Assessment of processes must address all relevant environmental issues of interest, but their life cycle stages are different. Unlike products life cycle stages, which are sequential, processes life cycle stages have only three main stages (Figure 2): resource provisioning and process implementation occur simultaneously; primary process operation and complementary process operation occur simultaneously as well, and refurbishing, recycling, and disposal is the end-of-life stage. The characteristics of these life stages are described below.

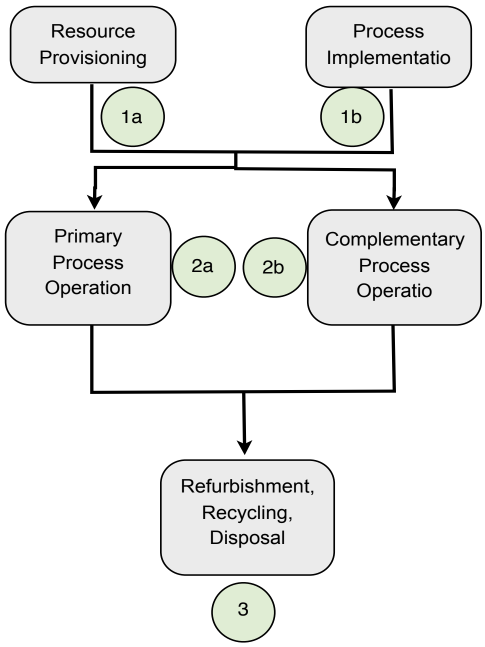


Figure 2: The Life Cycle stage of a process (own production adapted by Facility Assessment from the Life-cycle Perspective, 2010).

Stage 1a - **Resource Provisioning:** Regarding raw materials, which in many cases will be extracted from some natural reservoir, the first phase in the life cycle of any process is the input of materials used in the production of consumable resources throughout the assessed process life. Other consideration is the methods used to prepare materials to be used in the process. Supplier operations are thus an evaluation issue as the process is being developed and, later, as it is being used.

Stage 1b - Process Implementation: Similar to resource provisioning is process implementation, which considers the environmental impacts that result from activities necessary to manufacture the final product, process or service. These mainly involve the manufacture and installation of process equipment, and other required resources. This life stage has a strong commonality with the product evaluation stage.

Stage 2a - Primary Process Operation: The process or final product should be designed to be environmentally responsible in operation. Such a process would ideally limit the use of problematic or toxic materials, reduce energy consumption, minimize or avoid waste generation, and ensure that any residues produced can be used elsewhere such as in other industrial chain. Effort should be directed towards designing processes with secondary products which are saleable to others or usable in other processes within the same facility. In particular, the generation of residues or co-products as well as by-products with a toxicity level that renders their recycling or disposal difficult should be avoided. Since successful processes can become widely used throughout a manufacturing sector, they should be designed to perform well under a variety of conditions.

Stage 2b - Complementary Process Operation: Several manufacturing processes frequently form a symbiotic relationship with other processes, assuming and depending upon the existence of other similar or complementary processes. Thus, an adequate process evaluation must consider not only the environmental attributes or issues of the primary process itself, but also those of the complementary system that precedes and follows it (system expansion).

Stage 3 - Refurbishment, Recycling and Disposal: All process equipments or devices will eventually become obsolete, and must therefore be designed so as to optimize disassembly, and to recycle or reuse either their modules (the preferable option) or their materials. In this context, these processes are subjected to the same considerations and recommended activities that apply to any product with easily disconnected hardware.

2.1.2 – LCA: ISO standards and methodology

This section describes the internationally standardized methodological framework for life cycle assessment. The target audience includes LCA practitioners, and other environmental professionals with a strong interest in environmental assessment. As shown in Figure 3, the life cycle assessment framework is described by ISO in four main phases:

1) Goal and scope definition;
2) Inventory analysis;
3) Impact assessment;
4) Interpretation.

Therefore, ISO describes three extra points regarding LCA with greater detail: (1) Reporting/critical review, (2) Limitations of LCA and (3) Relationship with phases.

The double arrows between the phases indicate the interactive nature of LCA as illustrated by the following examples: when doing the impact assessment it can become clear that certain information is missing, which means that the life cycle inventory analysis (LCI) must be improved. Also, the interpretation of the results might be insufficient to fulfil the needs of the actual application, which means that the goal and scope definition must be revised by the expert who will carry out the study.

LCA's principles, procedures, methods and applications are presented based on the terminology and structure of the ISO Environmental Management Systems, tools and standards on LCA including general draft of environmental labels and declaration (table 1).

Table 1: ISO Environmental Management Systems, tools and standards on LCA (ISO 14040, 2006)

Environmental management	Life cycle assessment (LCA)- Requirements and guidelines, studies and life cycle inventory (LCI) studies. ISO 14044:2006
Environmental Labels and Declarations	Environmental Labelling-Self Declared Environmental Claims-Terms and Definitions (ISO DIS 14021). ISO/TC 207/SC3/WG2. (2002b)
Environmental Labels and Declarations	Environmental Labelling Type I - Guiding Principles, and procedures (ISO CD-2 14024). ISO/TC 207/SC3/WG1. (2001).
Environmental Labels and Declarations	Environmental Labelling Type III - Guiding Principles, and procedures (ISO pre-WD 14025). ISO/TC 207/SC3/WG1.
Evaluation of Environmental Performance (ISO CD 14031)	ISO TC 207/SC4/WGs 1-2. Life Cycle Assessment - Principles and Guidelines (ISO 14040). ISO TC 207/ SC5/WG1. (2006).

Environmental Management	ISO/TS 14048, Environmental management — Life cycle assessment — Data documentation format.
Environmental Management	ISO/TR 14049, Environmental management — Life cycle assessment — Examples of application of ISO 14041 to goal and scope definition and inventory analysis.

In summary, there is not a single approach to life cycle assessment. The technique can be applied with different levels of sophistication, as long as the life cycle approach to assessing choices is based on the first stage of LCA: the objective and scope. The key issue is life cycle global thinking, called Life cycle thinking. Regardless of the chosen level of sophistication, there are some basic requirements to the LCA.

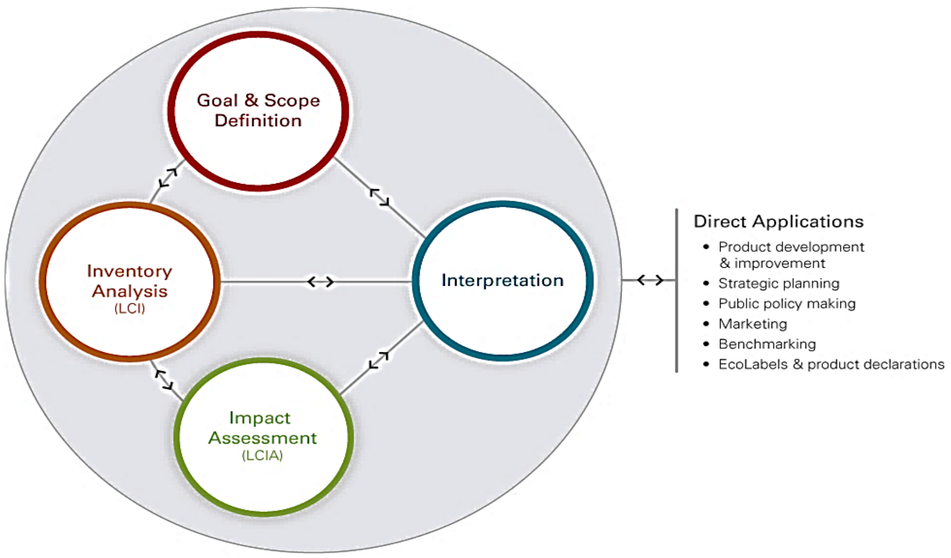


Figure 3: Life cycle assessment framework - phases of an LCA (ISO 14040:2006) (By Lcanz, 2016).

2.1.3 – ILCD Handbook: international series of technical guidence life cycle data system

The International Reference Life Cycle Data System (ILCD) has been established for guiding the development of consistent and reproducible, quality-assured life cycle data and robust assessments to be used in any sector, considering public and private sectors. This system consists primarily of the ILCD Handbook and the

ILCD Data Network. The Handbook is an international series of technical guidance documents (Figure 4). It has been developed through peer review and consultation and is in accordance with ISO standards 14040 and 14044, while it provides further specified guidance for better reproducibility and quality-assurance than the broader ISO basic framework can define. To facilitate this development, links have been established with National LCA Database projects in all parts of the world, and with the World Business Council for Sustainable Development (WBCSD) and the United Nations Environment Programme (UNEP), (Chomkhamsri et al., 2015).

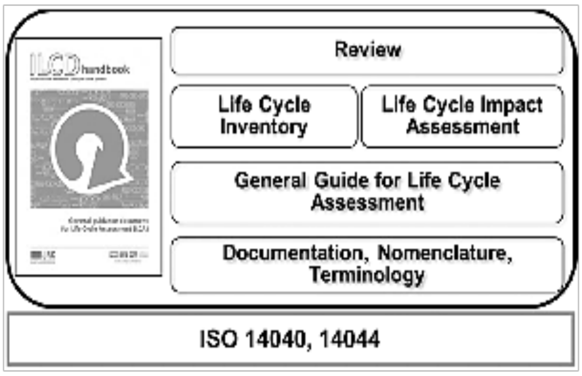


Figure 4: International Reference Life Cycle Data System (ILCD). From ILCD Handbook Guidance documents (2010).

Building on the ISO standard framework, the ILCD Handbook provides three separate documents: 1 - "Review schemes for Life Cycle Assessment (LCA)", 2 - "Reviewer qualification for Life Cycle Inventory (LCI) data sets", and 3 - "Review scope, methods and documentation", to address critical review in an LCA study and its applications.

The ILCD Handbook further specifies this, based on ISO 14044 and also ISO 14025. It provides guidance on minimum review type, reviewer qualification, and how to review LCA methods and technical information.

The first step is to identify the suitable review type as a minimum requirement for twelve applications ("cases"). To this end, the ILCD Handbook considers five criteria/factors:

1- Extent of stakeholder involvement
2- Complexity and broadness of the case

3- ISO standards requirement
4- Knowledge/experience of audience, and
5- Cost.

The analysis results shows that only two review types: 1 - “independent external review" and 2 - "independent panel review" are required and are hence recommended as the minimum requirement, depending on the case (European Commission, 2010b). In addition to the reviewer, interested parties shall be openly invited to participate in the process regarding LCA frameworks which could be differently applied in some cases. The accredited reviewer from a fourth party is not foreseen for the ILCD system (Chomkhamsri et al., 2015).

ISO standards 14044 and 14025 do not stablish fixed requirement on how to review each step of an LCA. Therefore, a separate document, which is part of the ILCD Handbook, allows a suitable set of guidelines for carrying out the actual Life Cycle Assessment (LCA) review, according to the different kinds of LCA applications. This issue will be further discussed to address new views of critical review requirements of LCA in Chapter 6.

Examples of methods to be applied in order to achieve a good review for each scope item are: 1 - Evidence collection by means of available documentation, 2 - Cross-checks with other sources, other similar processes or product systems and legal limits, 3 - Calculation of energy balance, mass balance, and chemical element balances, 4 - Sampling review (the number of random data selected should be representative) 5 - Plant visit, interview and, 6 – Critical review form expert. Table 2 provides the draft overview of the review methods and how they should be implemented (European Commission, 2010a).

Table 2: Draft overview of methods used for review (from ILCD handbook, 2010)

Methods		Implementation
Evidence collection by means of available documentation		Analysis of the documentation produced during the LCA work
Cross-checks	Cross-check with one or more other sources	Comparison with data and/or information on the issue, from another, independent source (can be both database and literature)
	Cross-check with one or more other process or product systems	Comparison with data and/or information on similar process or product systems, from the same or from other sources (can be both database and literature)
	Cross-check with legal limits	Comparison with applicable limits
Methods		**Implementation**
Verification and review of data source		Analysis of data source declared, checking its context-specific correct use as well as its relevance and quality.
Calculations	Energy balance	Calculation and analysis of energy balance
	Mass balance	Calculation and analysis of mass balance
	Element balances	Calculation and analysis of the context-specific relevant chemical element balances
	Other calculations	Verification and analysis of other calculation
Evidence collection by means plant visits and/or interviews		Interviews and/or plant visits should be performed in case of inconsistencies, uncertainties, or doubts. Persons to be interviewed need to have detailed technical expertise on the analysed process and issue
Expert judgement		Analysis by means expert opinions. The experts needs to have methodological and/or detailed technical expertise on the item to be verified and the process or product system in question as required to obtain a qualify expert judgement.
Conformity with ISO 14040 and 14044		Review against with the requirements set forth in ISO 14040 and ISO 14044.

2.1.4 - Advantages and limitations of LCA

The growing recognition of the importance of environmental protection and the potential impacts associated with produced and consumed products, processes and services has generated an increased interest in the development of methods for assessing the associated impacts and trying to mitigate them, and in doing so, improving economic aspects as well. One of the techniques being developed for this purpose is the Life Cycle Assessment (LCA), which studies the environmental aspects and potential impacts throughout a product or process life cycle. This methodology was developed in the sixties, when it became clear that the only effective way to analyse energy consumption in industrial systems from the environmental point of view, was to assess all stages of the process, from the extraction of the raw materials, their processing, transportation and use, ending with the return to the ecosphere of the generated waste. Initial studies were simple and generally restricted to energy needs calculation and to reducing solid waste (Miettinen & Hamalainen, 1997).

Key points have been identified over time for conducting a study of life cycle assessment, which must be defined (ISO 14040, 2006) at the start of any LCA project. These key points are:

- The product system functions, or the system comparative study;
- The functional unit used in each study;
- The product system to be studied;
- The system boundaries of the product or process;
- Allocation rules;
- Types of impact and methodology of impact assessment, and the subsequent interpretation to be performed in the assessment;
- Data requirements;
- Assumptions;
- System limitations ;
- The initial requirements of database quality;
- The type of critical review to be selected.

The life cycle assessment has a number of weaknesses that may affect the robustness of the final data, such as:

- The nature of the selections and assumptions made in the Life Cycle Assessment (i.e. system boundaries establishment, selection of data sources and impact categories) can be subjective (CML, 1992).
- The technique or models used for inventory analysis or to analyse environmental impacts are limited by their assumptions and may not be available for all potential impacts or applications.
- The results of LCA oriented to geographical correlation (global or regional area) may not be appropriate for local applications. For example: local conditions may not be adequately represented by regional conditions (Fullana & Rieradevall, 1997).
- The accuracy of LCA studies may be limited by data accessibility, availability, quantity and quality, for example: lack of national databases, types of data, aggregation, stockings, specific location and allocation (Fava & Page, 1992).
- The absence of geographical correlations (spatial) and temporal dimensions inventory databases used for impact assessment introduces uncertainty in the results of this impact. This uncertainty varies with geographical correlations and temporal characteristics of each impact category in each objective and scope.

ISO refers to the use of a functional unit, which indicates that the definition of the scope of a LCA study should clearly include product features. These identified features must be defined and quantified and a qualitative interpretation must be reported (Guiné et al., 2002).

The functional unit must be consistent with the objectives and scope of the study. One of the main purposes of the functional unit is to provide a reference for the normalization of input and output data related to a standard unit results. Therefore, the functional unit must be friendly, this means: to be clearly defined and to be measurable (ISO 14044, 2006). This is necessary to ensure the comparability of LCA results and applications. The comparability of LCA results is especially critical when analysing various systems to ensure that such comparisons are made on a common basis. The functional unit is usually functional (e.g.: 1 m^2 of surface, 1 m^3 of water, etc.). Normally, when a comparison must be performed, it is necessary to define a functional unit but many units are not actually clear and standard around the world (Such &Huppes, 2005).

On the other hand, it is also necessary to define the limits of the system under study. There are factors that impose these limits and they determine how different points should be introduced in an example of the unit processed on the Life Cycle Inventory. These characteristics include the planned implementation of the study (objectives and scope), the hypotheses, the exclusion criteria and data and the economic constraints. The selection of inputs and outputs, the level of aggregation within a data category and system modelling should be consistent with the study objective in the planning of the LCA study. The system should be modelled so that the inputs and outputs at its boundaries are elementary data flows. Criteria used to establish system limits should be identified and justified in the initial phases of the study. If the study aims to make public comparative assertions, the exclusion is justified by analysing material and energy flows, which is the case of the Environmental Product Declaration (EPD) (Lo Giudice & Clasadonte, 2010).

2.1.5 - Origin acceptability of data quality

The most widely used method to differentiate between source data of lower and higher quality is the data quality scoring system or data sensitivity analysis, sometimes called Pedigree matrices. It represents a basic requirement for the European Reference Life Cycle Data System (ELCD) through the International Reference Life Cycle Database (ILCD) data format and it is used in the Ecoinvent database through the ecospold formats and others. In the ELCD (European Commission Joint Research Centre – Institute for Environment and Sustainability, 2010), data quality scoring ranks flow data based on six indicators:

1 - technological representativeness, 2 - geographical correlation representativeness, 3 – time related representativeness, 4 - completeness, precision/uncertainty, and 5 - methodological appropriateness and consistency with likert range scores (i.e from 1 to 5, with a score of 1 representing the highest data quality, 5 the lowest and a score of 0 representing data quality that is deemed not applicable).

According to the ILCD method (ILCD, 2010), subjectivity is involved in the score assignement manner. It is most notably related to the interpretation of "high degree" and "sufficient degree" levels. For the most used comercial database, Ecoinvent, versions 1 and 2, repeatability was explored by Weidema (1996) and notable subjectivity was observed in information differentiation.

In Ecoinvent (versions 1 and 2) and ILCD scoring methods, much of the benefit provided by scoring is lost in the potential for inconsistent application of the scoring method. In version 3 of Ecoinvent, studied by Weidema et al. (2006), data quality scores are developed on a modified two (2) point scale when compared to the earlier versions:

1 - moving consideration of sample size from the scoring matrix to the specification of data percentage of the total activity sampled out as a part of modeling and validation, and
2 - rewording the reliability indicator description to avoid similarity between points in the scale (Cooper & Kahn, 2012).

2.1.6 - Attributional and consequential LCA

According to Ekvall & Tillman (1999), it is also useful to distinguish between attributional and consequential LCA models. The former is aimed at describing environmentally relevant physical flows to and from a life cycle (system boundary) and its subsystems, and the later is aimed at describing the environmental impact associated with these flows. The two models are described below in more detail.

Attributional LCA (aLCA) provides information about the impacts of processes used to produce (and consume and dispose of) a product, but does not consider indirect effects emerging from changes in the output of a product. The aLCA usually produces information on the average unit of a product. It performs comparisons between the direct impacts of products and thus, it is used to identify opportunities for reducing direct impacts in different stages of the life cycle (ISO 14044, 2006).

Consequential LCA (cLCA) contemplates environmental consequences resulting from a marginal demand change in the function provided by the product system. It includes only marginal suppliers in the inventory, and uses system expansion to solve multifunctionality. It considers processes that generate more than one co-product, usually defined as determining product and dependent product (Ekvall & Weidema, 2004; Weidema, 2006).
Decisions inspired by or based on LCA results are made after the study has been completed. For this reason, the use of LCA based scenarios is considered very relevant (Table 3).

Table 3: Key differences between aLCA and cLCA (Summarized from Brander (2008).

	Attributional LCA	Consequential LCA
Question the method aims to answer	What are the total emissions from the processes and material flows directly used in the life cycle of a product or process?	What is the change in total emissions as a result of a marginal change in the production (and consumption and disposal) of a product?
Application	aLCA is applicable for understanding the emissions directly associated with the life cycle of a product, is also appropriate for consumption based emissions accounting. Is not an appropriate approach for quantifying the change in total emissions resulting from policies that change the output of certain products.	The cLCA is applicable for informing consumers and policy-makers on the change in total emissions from a purchasing or policy decision and is not appropriate for consumption based emissions accounting.
System boundary	The processes and material flows directly used in the production, consumption and disposal of the product and process.	All processes and material flows, which are directly or indirectly affected by a marginal change in the output of a product or process.
Double-counting and accounting for absolute emissions	No double counting of emissions. The emissions allocated to one product in an aLCA will not to allocated to other products in other aLCA´s. If aLCA´s were conducted for all products the total of the results should be equal the sum of emissions from consumption.	Double counting of emissions. The scope of different cLCAs may superposition and the same emissions will be counted in multiple cLCAs. If cLCAs were conducted for all products the total of the results may be multiple times higher (or lower) than sum emissions from consumption.
Marginal or average data	aLCA tends to use average of data.	cLCA tends to use marginal data.
Market effects	aLCA does not consider the market effects of the process production and consumption of the product.	cLCA considers the market effects of the process production and consumption of the product.

	Attributional LCA	Consequential LCA
Methods	aLCA allocates emissions to co-products based on every economic, energy content, or mass value.	cLCA uses system expansion to quantify the effect of co-products on total emissions.
Non-market indirect effects	aLCA does not include other indirect effects.	cLCA should include all other indirect effects, such as the interactions with existing policies or process and product development.
Time-scales	aLCA aims to quantify the emissions attributable to a product at a given level of production at a given time.	cLCA target to quantify the change in emissions which result from a change in production. In this is necessary to specify the time line scale of the change.
Uncertainty	aLCA has low uncertainty because the relationships between inputs and outputs are generally "stoichiometric".	cLCA is almost always highly uncertain because it depend models that seek to represent complex socio-economic systems that include feedback loops and occasional elements.

2.1.7 – Detailed description of LCA application

2.1.7.1 - Simplified LCA

The simplified Life Cycle Assessment is an application of the LCA methodology used to perform a comprehensive previous assessment using generic data (qualitative and/or quantitative) and transportation or energy production standard modules, resulting in a simplified (not necessarily simple) assessment. For example, the study focuses on the most relevant environmental aspects and/or potential environmental impacts and/or life cycle stages and/or phases of the LCA and a thorough assessment of the reliability of the results (Christiansen et al., 1997).

In a simplified LCA, the goal of simplification is to essentially provide very similar results as a detailed LCA, but with a significant reduction in expenses and time. However, simplification presents a dilemma, because it is likely to affect the accuracy and reliability of the LCA results.

Therefore, the primary object of simplification is to identify the areas within the LCA that can be omitted or simplified without significantly compromising the overall result.
Simplification of LCA consists of three stages that are iteratively interlinked:

- Screening: To identify those parts of the life cycle or of the elementary flows that are really important or have some lack of data;
- Simplifying: To use screening findings in order to focus further work on the important parts of the system or the elementary flows;
- Assessing reliability: To check that streamlining does not significantly reduce the reliability of the entire result.

"Screening LCA" or "Streamlined LCA" are names often used as synonyms for a simplified LCA. However, a clear distinction should be made.

Screening as a part of the simplification procedure can help identifying the life cycle stages of a process/product system that can be left out in a simplified LCA. A screening LCA that already leaves out certain parts would not be adequate for identifying all the key issues, as it does not cover the full life cycle or all the environmentally important issues. In other words, the screening phase in a simplified LCA should be comprehensive in coverage, but may be superficial in detail of the real impact assessed.

A simplified LCA may be externally used if reported in accordance with the ISO standard requirements (ISO 14040, 2006). However, streamlining LCA is mostly used for internal purposes without formal requirements for reporting out of the company i.e. to EPD. To avoid results misinterpretation, the LCA user should be made explicitly aware of the limitations of the study (Christiansen, 1997).

2.1.7.2 - Complete or detailed LCA

In a complete LCA, the practitioner tabulates emissions and resource consumption, as well as other environmental exchanges at every relevant stage in a product's life cycle, from "cradle to grave". This includes extraction of raw materials needed to manufacture all the product's parts, energy consumption to transform materials, materials production, manufacturing, usage, recycling, and final disposal.

The Life cycle inventory (LCI) is an important phase of the LCA. It includes the compilation, tabulation, and preliminary analysis of all environmental exchanges (emissions, resource consumptions, balances, etc.). It is often necessary for practitioners to calculate, as well as to interpret, indicators of the potential impacts associated with such exchanges with the natural environment (Life Cycle Impact Assessment, LCIA).

The detail level in some of the applications is shown in Table 4. The contents of each of the applications are described in more detail in the following sections.

Table 4: Level of detail in some applications of LCA. (Adapted from EEA, 1997).

	Level of detail in LCA			
Application	**Conceptual**	**Simplified**	**Detailed**	**Comments**
Design for Environment	X	n/c		No formal links to LCA
Product development	n/c	X	n/c	Large variation in sophistication
Product improvement		n/c		Often based on already existing products
Environmental claims (ISO type II-labelling)	X			Seldom based on LCA
Ecolabelling (ISO type I-labelling)	n/c			Only criteria development requires an LCA
Environmental declaration (ISO type III-labelling)			n/c	Inventory and/or impact assessment
Organisation marketing		X	n/c	Inclusion of LCA in environmental reporting
Strategic planning	X	X		Gradual development of LCA knowledge
Green procurement	n/c	X		LCA not as detailed as in eco-labelling
Deposit/refund schemes		n/c		Reduced number of parameters in the LCA is often sufficient
Environmental ("green") taxes		n/c		Reduced number of parameters in the LCA is often sufficient
Choice between packaging systems	n/c		X	Detailed inventory, Scope disputed LCA results not the only information

(**X**=more common application and **n/c**= not common application of LCA level)

2.1.8 - Eco-labels perspective

The world population keeps growing and the food demand grows at the same pace. Nowadays, food production is becoming more and more globalised and industrialised, leading to its international standardisation; agricultural practices, specially in developed countries, have been intensified in order to increase the ratio yield/ha as much as possible. In this case, when talking about agriculture, organic agriculture or bio-agriculture is not included, and only the traditional methods are considered. Furthermore, globalisation has led to an increasing loss of local markets with a consequent increase in “food miles”, i.e. transport distances between farmers, manufacturing, and consumers, including waste and food losses with the consequences of social, economic and environmental costs (Notarnicola et al., 2012a; Reisch et al., 2013).

The need to increment agricultural production is one of the most severe problems the world is facing and recent statistical studies have reported that global population growth and changes of dietary habits in emerging countries over the next 40 years will cause an increase of about 60% in food, energy and water demands (Alexandratos & Bruinsma, 2012). At the same time, the depletion of fossil hydrocarbons will increase the demand for biofuels and industrial materials, which may compete with food for biomass. All these changes will cause a destabilisation of the sustainable use of natural resources, which will possible cause an increase in social and geopolitical tensions and will produce many kinds of crises (Notarnicola et al., 2012b).

In this research, the sustainable production of some product in concrete will not be considered, but in the world context, sustainable development and sustainable production and consumption in the Agri-food sector have been key issues. The above described situation has stimulated the creation of many international initiatives and strategies designed to reduce non-renewable resource consumption and consequently reduce environmental impacts deriving from food production and consumption, as well as to find more sustainable ways of production.

Europe has faced the need to stand out in the development of new strategies to obtain more productivity with less impact, due to the lack of enough land and to the increasing dependence of this region on food importation in the last decades. Since 2001, European governments have taken the initiative on sustainable development in order to define a strategy for strengthening and steering environmental policies towards a more ecological product market. This initiative is called Strategy for Sustainable Consumption and Production (SCP) and its main objective is to reduce the environmental, social, and economic impacts of products and services throughout their life cycle.

The European Union, by the Directorate General Joint Research Centre/Institute for Prospective Technology Studies (DG JRC/IPTS) launched a project called Environmental Impacts of Products (EIPRO) in an attempt to identify those products with the most relevant environmental impacts throughout their life cycle, following the basic LCA perspective from cradle to grave.

A public report presented by SCP 2006 concluded that there are three main areas which have the greatest impact: 1 – Agri-food industry; 2 - Private transport and 3 - Housing. Altogether, they are responsible for around 70–80% of consumption environmental impacts and account for around 60% of consumption expenditure. In particular, the Agri-food sector accumulates 20–30% of private consumption environmental impact (Tukker et al., 2006). This data attracted attention to the importance of controlling and improving food production environmental performance along the supply chain.

The European Technology Platform (ETP) created a Strategic Research Agenda (SRA) (2007–2020) for Food for Life which was published in 2007. It defined sustainable food production as the most important challenge that the European food industry will face.[2]

Other similar agendas around the world will not be described in this research. In Europe's case, land use represents a serious problem, and this fact contributes to the internationalization of food production. However, it is necessary to be aware of the type of production that is achieved in regions with lower technological level and lack of serious environmental policies, therefore generating higher environmental impacts.

In 2008, the European Commission (EC) published the "Action Plan for Sustainable Consumption and Production and on the Sustainable Industrial Policy" (SCP/SIP) (COM, 2008) in order to define the necessary interventions to implement the actual models developed for SPC:

(A) A dynamic framework was proposed for improving the energy/environmental performance of products during their life cycle,
(B) Increasing demand for better products and

[2] The newly revised Strategic Research and Innovation Agenda (SRIA) "2013–2020 and Beyond" now focuses specifically on innovation.

(C) Helping consumers make decisions regarding such products. This plan up until 2011, was considered an EU priority on the new environmental policies (Lo Giudice & Clasadonte, 2010).

2.1.9- Environmental product declaration and certification

The environmental assessment of a product can be done through an independent quality assurance process, also called certification, based on strict procedures and national or international criteria.

According to the ISO Standard 14020:2002 (ISO, 2002), voluntary environmental labels/declarations aim at "*encouraging the supply and demand for those products and services able to cause low damage to the environment so that it will stimulate a continuous environmental improvement process managed by the market*".

Three types of labels/environmental declarations have been identified and regulated:

1 - **Type I** (ISO 14024) (ISO, 2001), for example the EU Ecolabel or EU flower, the most widespread and well-known label;

2 - **Type II** (ISO 14021) (ISO, 2002), for example the "Mobius Cycle", related to the percentage of recycled material in a product and;

3 - **Type III** (ISO 14025) (ISO, 2006), for example, the International EPD® system, the most widespread and well-known declaration of this type. There is also another category, not regulated by ISO standards, which has been defined as "environmental label Type IV", for example the trademarks Forest Stewardship Council (FSC), Dolphin Safe and Fair-trade Global. The last two labels (IV, V) will not be discussed in this thesis.

Table 5 presents some of the main differences between environmental labels and environmental declarations.

Table 5: Differences between environmental product declarations and ecolabels.

Parameter	***Environmental declaration***	***Environmental labelling***
Type of LCA	Detailed inventory and impact assessment or simplified LCA	LCA used to pinpoint key features
Type of assessment	Neutral	Positive (evaluation by experts)
Number of products with declaration or label	All (in principle)	Only the best 10-30% of the product group
Target group	Wholesale dealers Professional buyers Environmentally conscious consumers	Consumers in general
Information level	Complex	Simple
Information content	Bar diagram and/or numbers suggested	Label
Comparative assertion possible	Yes, with two or more declarations available	No
Updating	With product changes	Variable, but the criteria are renewed every three years in many schemes

Type I label:

The most typical example of type I labelling oriented to consumers is the European Flower (Figure 5). Products that comply with the criteria of the European Flower label may, at a price, display the well-known label. Product criteria are established by the European Flower organization in cooperation with stakeholders. These criteria are periodically revised and made stricter in order to improve environmental performance by taking into account new technologies and best practices. ISO standard 14024 (2001) describes principles and procedures for type I environmental labelling. These eco-labelling schemes are briefly discussed in the following paragraphs; in addition, a short results description is presented of the feasibility study made for the possible extension of the "EU Ecolabel" to the Agri-food sector.

The programme objective is to encourage companies to rationally use resources and energy in order to design and produce environmentally friendly products, to guide consumers in choosing and identifying sustainable "green" products, and to promote conscious participation in environmental protection, both by businesses and the general public. As far as label types are concerned, two types, based on criteria defined by ISO standards 14020 and 14024, are available (Ecological Union, 2013).

The European Ecolabel represents the best European recognition of products, processes and services meeting specific environmental criteria and the highest environmental standards. These products, processes and services are characterised by their high performance and environmental quality. Obtaining such a label could help a product, process or service to emerge and differentiate itself on the market since the label certifies that it has a reduced environmental impact throughout its entire life cycle.

Figure 5**:** The Eurepean ecolabel logo - European flower (Earthsure, 2012).

Eco-labelling criteria include the following specific areas:

1. level of environmental pollution;
2. level of safety for human health;
3. content of recyclable/recycled components;
4. rational use of natural resources during the product's life cycle;
5. use of renewable resources during the product's life cycle;
6. waste management and;
7. use of the best available practices and technologies.

In 2013, only three criteria existed for the Agri-food sector: 1) STO −56171713–1.01– 2007 (Alcoholic beverages), 2) STO VL 2.02.9730–11–1.0 (Vegetables), and 3) STO VL 2.01.0131–10–1.0 (Drinking water).

Type II label:

This label represents a self-declaration and it can take many different forms. Type II declarations are based on single statements (e.g. % recycled) while type III declarations show a lot of information taking into account the results of the LCA performed specifically to the product.
Type II declarations are developed and issued by private companies and they are not supported by any government programs or official bodies, as is the case with type I and III declarations. Standard ISO 14021 (2002) gives guidance on how to develop type II declarations, for example by explaining how to use specific terms in a correct way when communicating products environmental performance (Figure 6).

According to Allison & Carter (2000) in the European Commission DG Environment final report, the Type II label could be an example of suitability because:

- It is potentially applicable to purchases by individuals as well as private and public organisations;
- It represents a guide for individuals to make quick purchase decisions and it has a high level of recognition;
- It is most suitable where there is a single significant environmental impact, as well as a high level of actual or potential consumer concern.

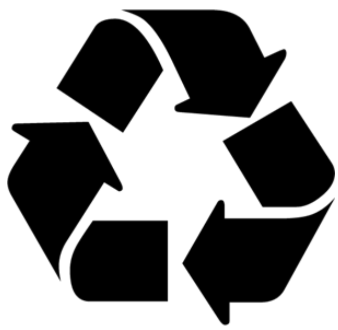


Figure 6: Recycled content, 2017

Type II and III labels on the Agri-food sector

In 2000, the scope of ecolabel type II (Council Regulation (EC) n. 1980/2000) was extended to be applied on services, and in 2010 the EC issued a new Regulation "Ecolabel III" (Council Regulation (EC) n. 60/2010) with the aim of:

- Streamlining the developing path for eligibility criteria by focussing on the most significant environmental impacts throughout the product/service's life cycle;
- Ensuring that the top 10–20 % environmental performers on the market could meet the criteria;
- Reducing costs of using the label to encourage the interested stakeholders to undertake the certification;
- Widening the label application field by evaluating the possibility of including food (under conditions emerging from a feasibility study). Ecolabel type III confirmed the application of environmental criteria to all consumer goods and services.

According with an exhaustive study by Oakdene Hollings Research and Consulting (2011), on the basis of the feasibility study results, the following recommendations were made:

- It is necessary to develop a credible multi-criteria overall outcome-based assessment system for primary production, something which is missing at the moment;
- It is necessary to clarify the legality of using the current Ecolabel and the term "ECO" when referring to food, feed, and beverages;
- If the use of a label is extended to non-organic products, it is important to conduct an appropriate communication in order to avoid consumers' erroneous interpretations;
- It is necessary to implement an economic assessment regarding the full public and private costs of implementing the European Ecolabel scheme.

The evolution of the LCA is connected to ecolabeling and EDPs. It is directly correlated with consumers' requests and the evolution of sustainable policies.
From October 2013, the European Ecolabel certification has been applicable to 26 categories of products/services (Oakdene Hollings Research and Consulting, 2011).

Type III and EPDs

The Eco-label Type III (better known as Environmental Product Declarations or **EPDs**) provide quantified and independently verified environmental information over the life cycle of goods or services (ISO 14025, 2006; Steen et al., 2008; Zackrisson et al., 2008). The EPDs are methodologically based on life cycle assessment. This methodology was standardized by ISO 14040 (2006) and ISO 14044 (2006) and developed according to a set of pre-defined product category rules (PCR).

The principles and procedures of the Environmental Product Declaration are defined and standardized by ISO 14025 (ISO, 2006).

According to Fet & Skaar (2006) and Fet et al., (2009), EPDs should enable comparison between products satisfying the same function. The use of this environmental declaration is a voluntary decision for the company (ISO 14025, 2006). The number of Type III programme operators, supervising bodies and development administrators of the Product Categorie Rules (PCRs), as well as EPDs verification under the Type III Environmental Declaration Programme has been growing, as knowledge about this declaration is increasing (Del Borghi et al., 2008; Strazza et al., 2013). This demand is observed particularly in the building and construction, automotive and food sectors (Braune et al., 2011).

Environmental labels in general can be used to highlight products' positive features and advantages which will positively impact the market, by providing transparent environmental information through environmental assessment. This is the most important reason why companies decide to invest in this declaration (Del Borghi et al., 2014). Nevertheless, the growing number of type III Ecolabels can also lead to market trade barriers (Bogeskar et al., 2002; Del Borghi, 2013). Moreover, in the last 5 years, Product Category Rules (**PCRs**) published by different programme operators are increasingly overlapping.

PCRs are sometimes set in a way that allows a broad understanding of the rules, leading to potential incomparability of EPDs based on the same PCRs (Fantin et al., 2012). This lack of detailed instructions and harmonized methodologies can lead to the creation of competitive advantages and misleading results (Dias & Arroja, 2012). As mentioned before, to ensure the practicability of using EPDs to compare products or processes, it is necessary to harmonize and standardize their development among programmes (Grahl & Schmincke, 2011), which may promote their global consistency and simplify their application to make it "friendly" (Ingwersen et al., 2012).

The Guidance for Product Category Rule Development (GPCRD, 2013) represents such a new approach, providing a step-by-step guidance for PCR development (Ingwersen & Subramanian, 2013) and it is applicable for all types of products (Figure 7).

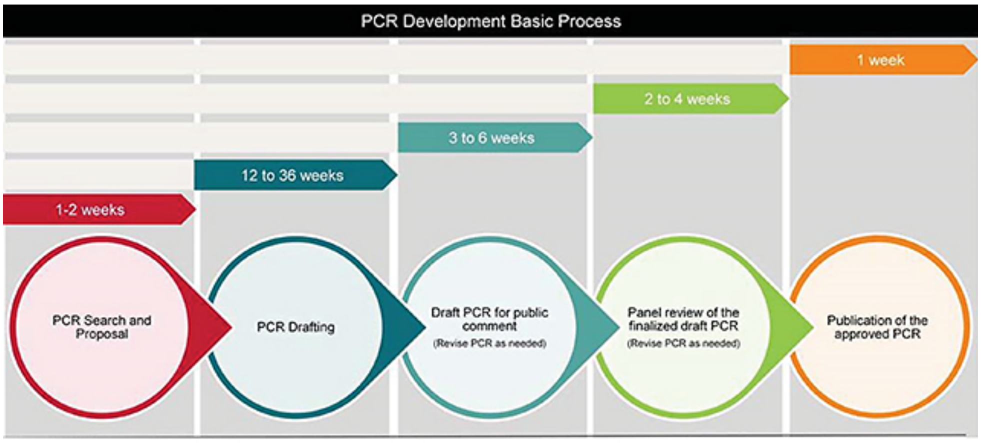


Figure 7: The timeline/process of a product category rule (PCR). (American Architectural Manufacturers Association (AAMA, 2015)).

After creating the specific Product Category Rules for a product, the next step is the implementation of the study and further certificate of the Environmental Product Declaration, which is represented in Figure 8.

Figure 8: Step representation of conducting EPD process. (GIGA, 2014).

The term EPD can only be used for declarations that comply with ISO 14025 guidelines and have been conducted and validated by the appropriate parties described above.

It is important to clarify that other types of environmental declarations of products and services exist around the world, but in this research the focus will be on EPD® and a case application of its use will be discussed (Table 6).

EPD Parties:

EPD Manager and Author: The EPD management and authorship is best conducted by an expert in order to ensure ISO compliance and acceptance by the Program Operator. The expert can be someone internal to the manufacturer for whom the EPD is being prepared. The expert can also be external to the company. The expert can not be the Program Operator.

Resources: *GIGA. LCA Practitioners.*

LCA Practitioner: Similar to EPD Management and Authorship, the Life-Cycle Assessment (LCA) is best conducted by an expert practitioner in order to ensure ISO compliance and acceptance by the Program Operator. The expert practitioner can be someone internal to the manufacturer for whom the EPD is being prepared. The expert can also be external to the company. The LCA Practitioner can not be the Program Operator.

Resources: *SRIBS (JKTAC), Ecovane, Quantis, PE International.*

Program Operator: EPDs require an independent third-party agency called the Program Operator, to verify that the full development process has been performed in accordance with ISO 14025 guidelines.

Resources: *Currently, the only Program Operator with experience in China is Underwriter's Laboratory Environment (ULE).*

The Agri-food sector is considered one of the largest sectors in which EPDs are applied. The second largest sector is the construction sector (EPD, 2016). According to Ingwersen & Subramanian (2013), an EPD report includes objectives, comparable and reliable information about the product’s environmental performance during its life cycle, and its environmental impacts.

Table 6: Current EPD systems available in the Agri-food sector in the world (Notarnicola *et al*., 2014b).

Name	Website
The International EPD® System	http://www.environdec.com/
EPD Norge	http://www.epd-norge.no/
Earthsure®	https://iere.org/programmes/earthsure/
Ecoleaf environmental label	http://www.ecoleaf-jemai.jp/eng/index.html
Sustainability measurement and reporting system (SMRS)	http://www.sustainabilityconsortium.org/smrs/

Regarding the advantages deriving from the adoption of an environmental management system, the Ecolabels and environmental declarations allow controlling and managing the environmental impacts related to activities and processes developed for production. In the EPD case, it is seen as a means of communicating the product's environmental performance during its life cycle with the from cradle-to-grave approach. Therefore, EPD represents an instrument which allows companies to give visibility to their own work, turning the environmental variables into competitive market factors (Meissner Schau & Magerholm Fet, 2008) (Figure 9).

To get an EPD, it is necessary to perform an LCA study (complete or simplified), and it must conform to certain product specific requirements and calculations known as product category rules (PCRs).

According to ISO 14025 (2006), a "Product Category Rules is defined as a set of specific rules, requirements, and guidelines for developing environmental declarations for one or more products that can fulfil equivalent functions, determining what information should be gathered and how that information should be evaluated: it allows fair comparison between similar products" (Lo Giudice & Clasadonte, 2010; Del Borghi, 2013).

EPD®

Figure 9: The International EPD logo (EDP, 2016)

The currently available EDP systems in the Agri-food sector are reported in Table 6.

The international EPD® system is the most widespread scheme. It was implemented in 1998 by the Swedish Environmental Management Council (SEMC) which, on behalf of the Global Type III Environmental Project Declaration Network (G.E.D. net), was appointed to oversee its harmonisation at international level. This process led to the creation of the Guidelines MRS 1999:2 "Requirements for Environmental Product Declaration, EPD - an application of ISO/TR 14025 Type III Environmental Declarations", which were replaced in 2008 by the new "General Programme Instructions for EPD" (Notarnicola et al., 2012b).

The EPD summarizes the entire sustainability history of a product in a single report including goals and scope, comparable and trustworthy information about the product's environmental accomplishment during its life cycle, and its impacts. It is possible to include many kinds of impact categories depending on the need to include corporate social responsibility (Meissner Schau & Magerholm Fet, 2008).
The changes aimed at making the product label consistent with the new ISO Standard 14025:2006 and also at encouraging global diffusion of EPD and harmonisation with the existing environmental labels/declarations.

Analysing the official information from the International EPD® System, as of November 2016 there are **660** products certifications (including precertification) registered in 33 different countries (Figure 10). From the total of product EPD certifications registered in the world, **138** come from the Agri-food industry (see red bars).
The first 20 countries were chosen to graphically map the current situation of EPD in the planet.

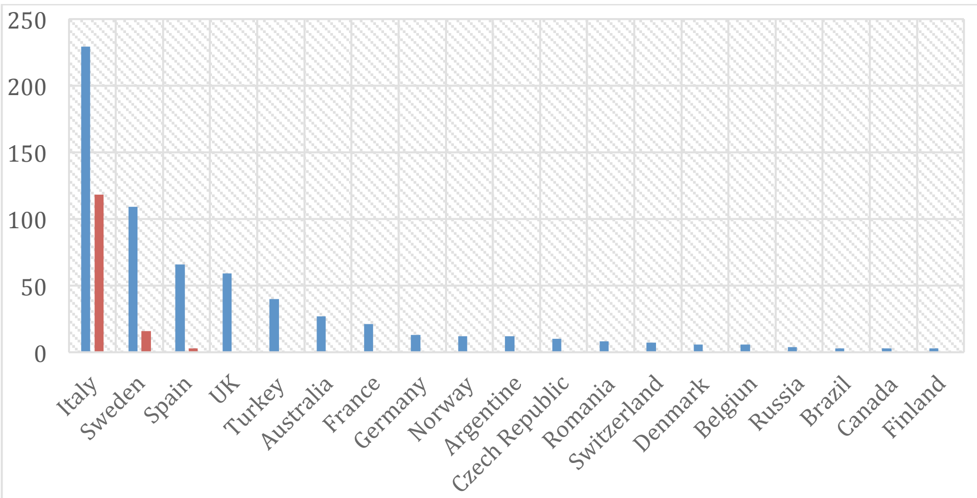


Figure 10: Agri-food EPD´s® certifications in the world.

This thesis focuses on the Agri-food sector and the main "umbrella" of the research is to promote sustainability through tools such as LCA and EPDs. Strategies for sustainable development have to face many environmental problems such as climate change, energy and water scarcity, biodiversity loss, deforestation, pollution, land and soil erosion, and desertification. In this context, specific indicators were established with the aim of assessing these impacts, trying to reduce them and, at the same time, maintaining economic and societal well-being.

2.1.10 - Impact assessment in LCA

The type, significance and magnitude of environmental impacts or the associated costs of specific life cycle activities are identified during the Life Cycle Impact Assessment (LCIA) phase (Pennington et al., 2004b). This is accomplished by using the quantitative information obtained in the previous stage, the Life Cycle Inventory (LCI), using impact categories and their associated category indicators (quantifiable resources/emissions/substances representing each impact category) (Guinée et al., 2011).

ISO defined both mandatory and optional elements of the LCIA framework. The mandatory elements are defined by selecting impact categories, category indicators and characterization models; the classification of LCI results and the calculation of category indicators results.

The optional elements are defined by the magnitude calculation of the category indicators results relative to reference information or normalization; weighting; grouping; and data quality analysis (Guinée et al., 2011). Additionally to these optional elements, the ISO described extra points to be included in the study which were researched in this thesis. These extra points are: (1) Reporting/Critical Review, (2) Limitations of LCA, (3) Relationship with other phases. These impact categories are very vast and, depending on the scope and nature of the study are generally sub-divided to represent more specific impacts. The European Environment Agency (Jensen & Remmen, 2006) identifies and determines priority impact categories such as: global warming potential or climate change, acidification, eutrophication, abiotic resources, biotic resources depletion, land use issues, photochemical oxidant formation, stratospheric ozone depletion, eco-toxicological impacts, human toxicological impacts, and the human work environment. With the exception of the latest one, most of these categories are commonly employed in published LCA studies, including those in the Agri-food sector (Table 7).

Table 7: Impact categories commonly employed in published LCA research (based on: Pelletier et al., 2007).

Impact Category	Description of Impacts
Climate Change	A change in global or regional climate patterns
Acidification	Contributes to acid deposition
Eutrophication	Provision of nutrients contributes to biological oxygen demand
Human Toxicty	Contributes to conditions toxic to humans
Photochemical Oxidant Formation	Contributes to photochemical smog
Aquatic/Terrestrial Ecotoxicity	Contributes to conditions toxic to flora and fauna
Energy Use	Contributes to depletion of non-renewable energy resources
Ozone Depletion	Contributes to depletion of stratospheric ozone
Biotic Resource Use	Contributes to depletion of renewable resources
Abiotic Resource Use	Contributes to depletion of non-renewable resources

Many impact categories commonly used in all LCA studies are also used in the Agri-food field and as it is shown below.

Substances contributing to the impact category of the 5 more common used categories in Agri-food LCA studies (ILCD, 2010).

- The substances normally considered as contributors to **Climate Change /Global Warming Potential** are:

• Carbon dioxide (CO_2)	• Methane (CH_4)
• Nitrous oxides (N_2O)	• CFC's (CFC-11, -12, -113, -114, -115)
• HCFC's (HCFC-22, -123, -124, -141b, -142b)	• HFC's (HFC-125, -134a, -152a)
• Halons	• Tetrachloromethane (CCl_4)
• 1,1,1-Trichloroethane (CCl_3CH_3)	• Carbon monoxide (CO)

- The substances normally considered as contributors to **Acidification** are:

• sulfur dioxide (SO_2)	• sulfur trioxide (SO_3)
• nitrogen oxides (NO_x)	• hydrogen chloride (HCl)
• nitric acid (HNO_3)	• sulfuric acid (H_2SO_4)
• phosphoric acid (H_3PO_4)	• hydrogen fluoride (HF)
• hydrogen sulfide (H_2S)	• ammonia (NH_3)

➢ The substances normally considered as contributors to **Human Toxicity** are:

- nmVOC from road transport
- Nitrous oxides (NOx)
- Volatile organic compounds (VOC)
- Persistent organic pollutants (POP)
- Heavy metals (cadmium, lead, mercury, etc.)
- Sulfur dioxide (SO2)
- Chlorinated organic compounds
- Particulate matter (PM10)

➢ The substances normally considered as contributors to **Ecotoxicity** are:

- Organotin compounds
- Organic substances/persistent organic pollutants (POP)
- Metals
- Pesticides

➢ The substances normally considered as contributors to **Land Use** are:

- Urban Land Use
- Agricultural Land Use

This chapter contains a summary description of currently available Life Cycle Impact Assessment methodologies used on LCA projects (Table 8).

An important goal of this part of the thesis is the presentation of impact categories that deserve special attention for further development.

The main focus is on describing commonly used characterization methodologies, but in this thesis the focus will be only on the ReCiPe methodology, because in the literature review from Agri-food LCA projects, it was observed that ReCipe was the most common methodology used and it is also the most current one.

Table 8: List of more common LCIA methodologies (ILCD handbook, 2010).

Methodology	Developed by	Country of origin
CML2002	CML	Netherlands
Eco-indicator 99	PRé	Netherlands
EDIP97 – EDIP2003	DTU	Denmark
EPS 2000	IVL	Sweden
Impact 2002+	EPFL	Switzerland
LIME	AIST	Japan
LUCAS	CIRAIG	Canada
ReCiPe	**RUN + PRé + CML + RIVM**	**Netherlands**
Swiss Ecoscarcity 07	E2+ ESU-services	Switzerland
TRACI	US EPA	USA
MEEuP	VhK	Netherlands

The analysis leads to a pre-selection of characterization models for the individual impact categories that are currently used and which are appropriate for use in the context of life cycle assessments (Table 9).

Table 9: Pre-selection of characterization models for further analysis (ILCD, 2010).

	Climate change	Ozone depletion	Respiratory inorganics	Human toxicity4	Ionising radiation	Ecotoxicity	Ozone formation	Acidification	Terrest. Eutrophication	Aquatic Eutrophication.	Land use	Resource Consumption	Others
CML2002	O	o		M	o5	o	M	M	M	M	o	M	
Eco-indicator 99	E	E	E	o	o		E	E	E		E	E	
EDIP 2003/EDIP97[6]	O	M	o	M	o	M	M	M	M	M		M	Work environ-ment Road noise
EPS 2000	E	E	E	E	o	E	E	o	o	o	E	E	
Impact 2002+	O	o	E	M E	o	M E	E	M E		M E	o	E	
LIME	E	E	M	E		o	M E	M E	o	E	E	E	Indoor air
LUCAS	O	o		o		o	o	o	o	o	o	o	
MEEuP	O	o	M	M		M	M	M	M	M		water	
ReCiPe	M E	E	M E	M E	o	M E	M E	M E	o	M E	M E	E	
Swiss Ecoscarcity 07	O	o	o	o	M E	M	o	o	o	o	M E	water	Endo-crine disrupt-tors
TRACI	O	o	M	M		M	M	M	o	M		o	
Specific methods to be evaluated	Ecological footprint		7	USETox		USETox		Seppälä		Payet	Ecological footprint	deWulf et al.	Noise Müller Wenk
Specific methods of potential interest (not to be evaluated)				Watson (Bachmann)	Ecotoxicity of radiation (Laplace et al.)		EcoSense (Krewitt et al.)	EcoSense (Krewitt et al.)		Kärrman & Jönsson	8		Meijer indoor air UNEP Indoor air (Bruzzi et al., 2007)

o: Available in the methodology, but not further investigated
M: Midpoint model available and further analysed;
E: Endpoint model available and further analysed

The ReCiPe methodology can be considered as the successor of the Eco-indicator 99 and CML-IA methods. Its initial proposition was to integrate the "problem oriented approach" of CML-IA and the "damage oriented approach" of Eco-indicator 99, which are the two most widely used methodologies. In essence, the "problem oriented approach" defines the impact categories at a level of midpoint.

All results present a level of uncertainty and for this point the uncertainty is relatively low. This solution conducts to many different impact categories which makes drawing conclusions with the obtained results fairly complex.

The damage oriented approach of Eco-indicator 99 methodology results in only three impact categories, which makes the interpretation of the results easier. Nevertherless, the uncertainty level in the final results calculation is higher.

ReCiPe implements both strategies and has both midpoint (problem oriented) and endpoint (damage oriented) impact categories. The midpoint characterization factors are multiplied by damage factors, to obtain the endpoint characterization values. ReCiPe comprises two sets of impact categories with associated sets of characterization factors (ILCD, 2010).

At the midpoint level, 18 impact categories are addressed: 1. Ozone depletion, 2. Human toxicity, 3. Ionizing radiation, 4. Photochemical oxidant formation, 5. Particulate matter formation, 6. Terrestrial acidification, 7. Climate change, 8. Terrestrial ecotoxicity, 9. Agricultural land occupation, 10. Urban land occupation, 11. Natural land transformation, 12. Marine ecotoxicity, 13. Marine eutrophication, 14. Fresh water eutrophication, 15. Fresh water ecotoxicity, 16. Fossil fuel depletion, 17. Minerals depletion and 18. Fresh water depletion (Figure 11).

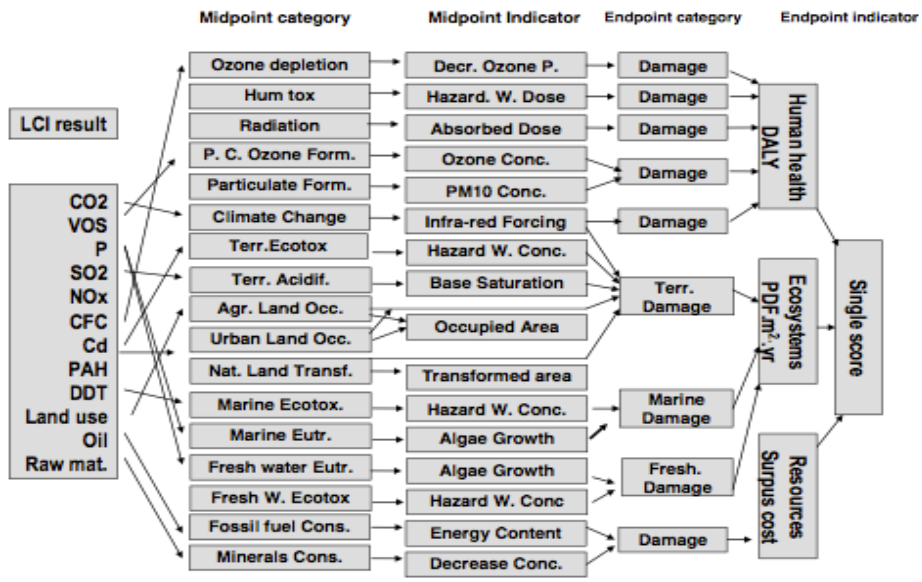


Figure 11: Impact categories and pathways covered by the ReCiPe methodology (ILCD handbook, 2010).

2.2 - Stakeholder theory and social network analysis applied to environmental issues

2.2.1 - Stakeholders concept

The term stakeholder was chosen as a literary device to question management´s unique emphasis on stockholders (Freeman, 1999) and instead suggests that the firm has a responsibility with a variety of stakeholders and without the support of the primary stakeholders, the company would not survive.

The initial issue in stakeholder management is correct stakeholder identification, and the term has been defined in many ways (Mitchell et al., 1997) beginning with studies conducted by Freeman (1984). The traditional definition of a stakeholder is "any group or individual who can affect or is affected by the achievement of the organization's objectives". In general, this concept represents a redefinition of the organization.

The purpose and character of the organization as well as the managers' roles are very unclear; they have been contested in the literature and have changed over the years. Even Freeman changed his definition over time and one of his latest definitions describes stakeholders as "those groups who are vital to the survival and success of the corporation" Freeman (2003).

According to this concept, Friedman and Miles (2006) mention that the Normative Stakeholders Theory contains ideas of how managers or stakeholders should act on behalf of the organization, always using ethical principles.

The general stakeholder concept described by Freeman (2006), is applied to LCA stakeholders, whereas, the process of obtaining data (LCI), comparing data (LCIA), using and interpreting these data is complex and involve many actors, especially those that are directly related to the study's objectives and scope (Miller & Olleros, 2000).

As open systems, products and projects (specially big projects) have a representative impact and are subjected to wide socio-political and environmental demands and pressures stemming from external stakeholders such as regulatory agencies, community groups, environmentalists, local and affected residents, local and national governments, etc. (Winch & Bonke, 2002; Floricel & Miller, 2001; Morris & Hough, 1987; Morris, 1982). Such stakeholders could be actors in the environmental project that are not formal members of the project but may influence it or be affected by it either directly or indirectly (Winch, 2004).

In many cases, a lack of understanding of the various stakeholder groups could influence the project life cycle's final results which lie under the management's influence (IFC, 2007; Miller & Olleros, 2000; Winch & Bonke, 2002). However, some empirical studies have acknowledged the challenges and conflicts that have emerged from the project's external stakeholders (Flyvbjerg et al., 2003; Miller & Olleros, 2000; Morris & Hough, 1987).

2.2.2 - Stakeholders management

According with Partridge et al. (2005), in order to engage each stakeholder the project team must understand the needs and requirements of each actor and try to address them from the project output. Accordingly, the PMBOK (2008) has included stakeholder management as a separate knowledge area, based on its importance in a given project context. To ensure that all stakeholders are informed of the project progress, project managers need to provide regular or periodical updates to all the managed stakeholders.

Managers are expected to share information progress and project issues concerns with all the involved actors, for which the project team needs to establish good communication channels.
The need for stakeholders' engagement has acquired importance due to the increased challenges of the project manager in today's innovation and technologic environment while managing complexity, including the complex cases of LCA studies.

2.2.3 - Stakeholders analysis

According to the Department for International Development of the UK (IDDUK, 2003), the two fundamental objectives of the stakeholder analysis are:

1- Improvement of policies and projects effectiveness through the explicit consideration of the actors' interests and
2- The identification and management of potential conflicts produced by a particular topic, as well as addressing the distributional and social impacts of policies and projects, separately assessing the interests of stakeholders and impacts exerted on each of them.

Rietbergen-McCracken and Narayan (1998) stress the importance of identifying and characterizing actors in order to diagnose how a particular action, project or program may affect the interests of each stakeholder, either to gain their positive influence to the common interest issue, or to avoid their opposition.

Figure 12 summarizes the steps proposed by Rietbergen-McCracken (1998) to develop a stakeholder analysis. It comprises four main steps to identify actors, assess their interests, influence and importance, and design a plan to facilitate their participation in any project or program.

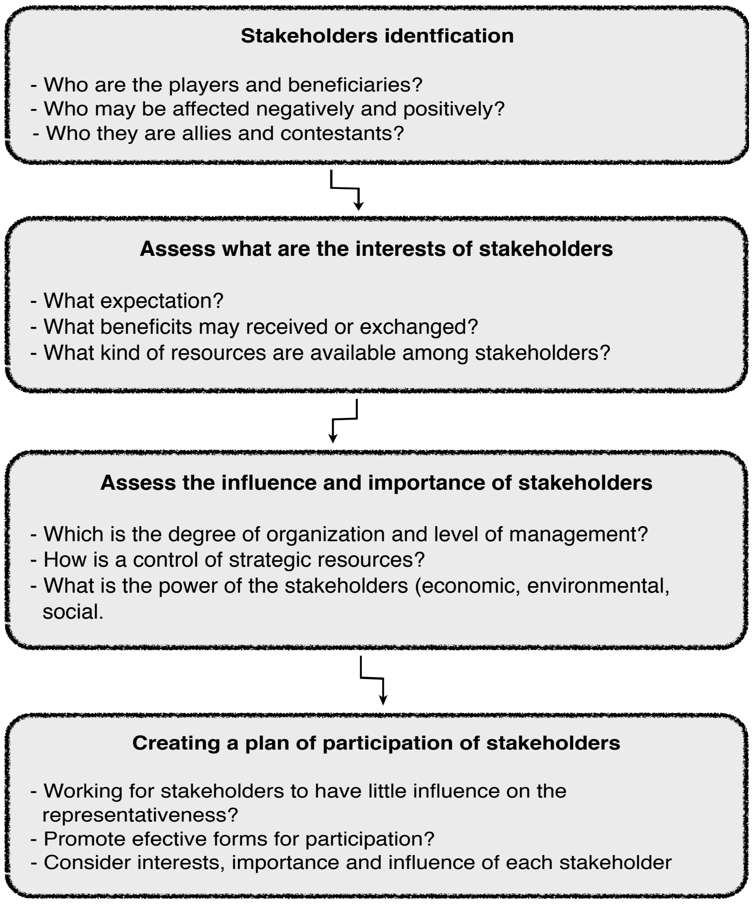


Figure 12: Key steps in the stakeholder analysis. Adapted from Rietbergen-McCracker & Narayan, 1998.

2.2.4 - Research on stakeholder analysis and external stakeholders influence.

External stakeholders may affect the project, or are affected by the project, so they constitute a relevant part of an environmental project. One of the goals of this thesis is to contribute to project research by providing new valuable information (qualitative and quantitative) and theoretical understanding of how stakeholders influence an LCA study and how to manage external stakeholders in the context of sustainable projects. In addition, this research will examine the impact of selected contextual factors, project life cycle phase, project management interpretation processes and local stakeholders' network structure, as well as the stakeholder behaviour, the entropy of the LCA simplification process and its management. Thus, the final objective of this thesis is the proposal of a Good Practices Manual to achieve a minimum standard quality level for the implementation of an LCA in the Agri-food sector. Additionally, a contribution will be made to extending project research by increasing the current understanding of the LCA stakeholder behaviour and corresponding managerial responses through the empirical study of different projects in Brazil and Spain.

Furthermore, the results of this study could support the development of more effective stakeholder management approaches in Life Cycle Assessment studies. These results could be implemented in all types of studies, but in this case they will be applied to the Agri-food sector.

The primary theoretical perspective used in this thesis is the stakeholder theory, applied in the context of project stakeholder research. The established theoretical framework of the stakeholder theory will be used for the investigation of LCA projects. The basic assumption of the stakeholder theory is that a focal organization has established relationships with many groups and organizations belonging to its external environment. The stakeholder theory has been selected because it is a central theoretical perspective used to study stakeholders and it provides a solid starting point for identifying and classifying LCA projects in order to understand their behaviour and requirements for information exchange. Also, perspectives on this area in Brazil and Spain will be analysed. After this holistic investigation, the Life Cycle Assessment and Environmental Product Declaration of selected study cases from Agri-food industry will be addressed.

2.2.5 - Stakeholders in Life Cycle Assessment

Conceptually, Biswas et al. (1998) classified LCA stakeholders in four categories: (1) LCA method users; (2) LCA results users; (3) beneficiaries or victims of impact/study or; (4) experts in the definition of either type of relevant impact and researchers conducting studies to improve LCA methodology. For many authors, stakeholders' participation increases the credibility of LCA results (Baldo et al., 2002).

The nature of an LCA stakeholder can range from those having an equity stake to a scenario with players having a high level of influence due to economic, technical or market influence over the institution or organization (Freeman, 1999). In some cases, governments can exert a strong influence over the market and, consequently, over private institutions.

Stakeholders participation on the evaluation process is interesting for many reasons and it can guarantee a final set of better quality indicators which reflects the stakeholder values (Rosenström & Kyllönen, 2007; Mendoza & Prabhu, 2000). Rowe & Frewer (2000), state that the quality of the participatory arrangements, in terms of procedures credibility and organizations quality, determines the quality of the study results.

Institutions lean on the continuous participation of primary stakeholders (e.g. employers, investors, customers and suppliers) and secondary stakeholders (e.g., those who influence or affect, or are influenced or affected by corporations, but are not engaged in direct transactions with them and are not essential for their survival) (Freeman, 2010; Clarkson, 1995). This general concept and classification can also be applied to Life Cycle Assessment (LCA) stakeholders. These secondary groups are not essential for the organizations basics functions, but they can strongly influence how companies are perceived by governments and public institutions. Therefore, they can have a major impact on any life cycle analysis process or life cycle assessment of an organization through stakeholders interactions (Clarkson, 1995).

One of the main ways of disseminating research findings and case studies related to LCA is through the publication of articles in scientific journals, in order to achieve credibility and quality parameters. These publications complete the scientific communication cycle (research; dissemination; reading; validation and peer acceptance) promoting science progress through the generation of new knowledge or the application of produced knowledge in the LCA field and thus, they are useful both for academia and for industry (Oliveira, 2005).

Balancieri et al., (2005) state that scientific collaboration can be seen as a cooperative enterprise which deals with common goals, coordinated efforts, and objective outcomes or products, and with shared responsibilities and merits. It offers an opportunity for improving results and maximizing the potentials of scientific production, although scientific collaboration can occur through formal or informal relations (Cronin et al., 2003; Laband & Tollison, 2000).

Stakeholders' relationship and information sharing on an LCA project in an industrial field is not the same as in the academic field. Companies, in many cases, perform an LCA study but decide not to publish the results following scientific procedures due to fear that the information might be used against the company (Willers & Rodrigues, 2014). Nevertheless, due to the increased demand for environmentally friendly products and services, more companies have adopted this type of environmental communications for marketing purposes.

Since the beginning, experts have been traditionally written about and discussing LCA inside universities, or in R&D laboratories, but with little public diffusion, let alone consultation. But as practitioners understand the need for increased credibility of the tool and greater acceptance by the public, this arrangement is changing and information efforts are growing around the world. As a result, there is now a greater curiosity about what other people think about the Life Cycle Assessment, and about its implications and consequences for the future. Addressing this issue, the Society for the Promotion of LCA Development (SPOLD), reached some conclusions in 1995, in their study "Synthesis Report on the Social Value of LCA". This study can be summarized as follows:

- Global knowledge about LCA remains worryingly low in the general public, even if it is growing;
- LCA, in its various forms, is now seen by stakeholders as a necessary, integral part of environmental management and a strong impact assessment tool;
- LCA remains in the early stages of development, with a good deal of further development needed to concretize a basic method to assess environmental issues;
- The involvement of external stakeholders in defining study boundaries and stimulating 'out-of-the-box' thinking is seen to be increasingly important.

- The level of progress and use differs among countries, but overall the rate of development in the LCA field is slowing as consolidation of methodologies begins;
- A major concern expressed by a high proportion of practitioners and experts in LCA is that quality control mechanisms remain relatively weak and that a long time is needed to perform a complete study.

By analyzing the literature, 7 main groups of LCA stakeholders were identified:

1 - Universities and Research Institutes

This category is probably the most active because methodology research and improvement as well as the analysis of different LCA applications are normally performed by academics. However, this category is at the same time divergent where standards, modeling and methodology consensus are concerned.

2 - Consultants

Among all stakeholders and LCA users, consultants are very optimistic about the agreement that a key challenge for continued growth is the future of LCA. One factor at work is that the potential benefits of LCA vary considerably between industry sectors, academy, markets and countries. But for the most part, consultants enhance LCA credibility.

3 - Financial institutions

One of the most important problems in LCA, is that leaders have been ahead of consumer demand, and have not had the expected market response. For these stakeholders, financial institutions and analysts would ideally be able to compare and benchmark all information, especially the economic relationships.

4 - Governments

Through regulations, environmental studies, eco-labelling initiatives and life cycle thinking, governments clearly have an important role to play. Increasingly, in Europe some government agencies will require LCA data results to support their decision-making processes, as it is the case of the Denmark Government. In the near future, although it is still common to regard LCA as a tool for assessing products, process and services, it is very likely that it will be used for government decision making and industry policy making.

5 - Industry Associations

Various industry and also commerce associations' respondents foresee that there would be growing pressures for benchmarking against industry averages. Sharing internal data is normally very sensitive, but many companies are happier to supply data when they know they will be aggregated. Industry associations will increasingly be required to supply aggregated data both to member companies and to client industries and regulators. Overall, these associations are expected to play a central role. One way to overcome the fear of data sharing is to help industry understand the true value of LCA in the future, and this is one of the roles that industry associations could assume.

6 - NGOs

The non-governmental organizations (NGOs) have a potentially critical role in the interaction and intermediation of LCA among governments, consumers and industry. Several papers and reports see NGOs as playing more of a representative, challenging role than a direct contribution to such areas as the formulation of corporate strategy.

Because they are supposed to be neutral, NGOs involvement can bring benefits such as adding weight to public acceptability of LCA work results and adding greater corporate transparency by demanding more data.

7 - Consumer Associations

Consumers have an essential role and often have the ultimate say in which products survive and which do not. Some respondents were optimistic that consumers would play an increasingly important role in this field. And where the Agri-food sector is concerned, the issue could be more sensitive because consumers are eating the analyzed products.

2.2.5.1 - Stakeholder identification

Proper identification and classification of LCA stakeholders is critical when performing an LCA study for private or academic developers. Stakeholder decisions or requirements are influenced by the importance of the study goals, which is a function of their power and the legitimacy of the study scope. Power and legitimacy will be different for primary, secondary and non-stakeholders influence, therefore the impact and efficiency of an LCA study can be better understood if stakeholders are correctly identified and classified (Boonstra, 2006; Clement, 2005; Lim et al., 2005).

Identification of external influences in an LCA study is a key aspect for its quality, but it is often overlooked. These influences can be exerted for example, by customers or by governmental agencies. Moreover, customers can also exercise political power by filing complaints with customer or public agencies to verify some environmental impact in any product or service (Preble, 2005). These actors can assist LCA researchers and developers to support and identify what kind of requirements and powers stakeholders possess and their role and responses in the LCA study (Table 10). In this role, some requirements and issues were identified for LCA stakeholders in Brazil and Spain: (1) different LCA software, (2) data units, (3) environmental indicators, (4) database quality (5) allocation, (6) sensitivity analysis, (7) data availability, (8) confidentiality, (9) system boundaries, (10) system limitations, (11) results interpretation, (12) marketing of LCA results, (13) legal requirements, (14) internal sustainable policy, (15) customer restrictions, (16) environmental information sharing, (17) data sharing barriers, (18) scientific contribution, (19) internal relationship and (20) external relationship.

In addition to the highlighted influences, relationships and requirements of stakeholders, the first phase of this study aims to identify academic and industrial LCA stakeholder's requirements; to analyse, using a Social Network Analysis tool, how they relate with other sectors; and how the information exchange works among each other, as well as to present an interpretation of academic and industrial LCA stakeholders' differences in Brazil and Spain. The relationship between all the stakeholders involved is important to assess the quality and quantity of environmental information, to identify the real goals, the role of this tool in each study and what to do with the results.

Table 10: Review of LCA stakeholders requirements.

Stakeholders	Biswas et al., (1998)	Baldo et al., (2002)	James, Grant, and Sonneveld (2002)	Norris (2006)	Dreyer, Hauschild, and Schierbeck (2010), Hunkeler (2006)	Benoît et al., (2010)	Reitinger et al., (2011)	Kuczenski, Sahin, and El Abbadi (2016)
Workers					x	x	x	
Consumers	x	x				x	x	
Local community						x	x	
Society				x		x		
Industry associations			x					x
Governmental organizations	x		x					x
Project sponsors			x					
Non-governmental associations		x	x					x
LCA experts	x							x
Private sector	x							x

Once the overview and research of real LCA stakeholders was performed, the stakeholders were identified, interviews were conducted and questionnaires were applied in Brazil and Spain. This assessment was performed using scientific articles and personal information from LCA experts in both countries and could be resumed in table 11.

Table 11: Interest LCA stakeholders in Brazil and Spain.

Stakeholders	Primary interest
Universities	Improve the LCA methodology, find governmental and private funds to realize LCA studies, form students in LCA
Research Centres	Do LCA studies to public sector and private sector
Companies/Factories	Contract LCA studies for some product or process from your fabric
LCA Consulting Companies	Sale LCA study to private companies and policy making to governments
Government	Contract and foment LCA methodology and application improvement

2.2.5.2 - Research on stakeholder behaviour

One of the main ways of disseminating research findings and case studies related to LCA is through the publication of communications in scientific journals. According to Klöpffer (2007) "Modern science and publishing requires enough information to repeat experiments and to fully understand theories." Scientific publications are an important source of information sharing in order to identify the development of LCA knowledge around the world and to understand how research is organized and structured in this field of knowledge.

Each scientific community shares generalizations, values, methods, beliefs, and a historical context that lead to a convergence of judgments into the industrial and social group. The only way to gain access to this community is through a socialization process in the environment of that community (Kuhn, 2006).

Mattedi & Spiess (2010) state that production and transmission of scientific knowledge is a social activity that involves integrating scientific, industrial, business and cultural communities. They indicate that the effects of the process of integration and operation of the scientific community impact the teaching/learning relations, better production and the social context.

Balancieri et al., (2005) state that scientific collaboration can be seen as a cooperative enterprise that deals with common goals, coordinated efforts, and objective outcomes, proceses or products, with shared responsibilities and merits. From this relationship the opportunity arises for improving results and maximizing scientific production potential and real application discoveries. Scientific collaboration can occur through formal or informal relationships (Cronin et al., 2003; Laband & Tollison, 2000). In establishing relationships and sharing information of an LCA project on the industrial field, the same connection does not occur, when comparing with academic stakeholders. Companies perform LCA studies, but in many cases they do not publish results due to the fear that the information could be used against the company. From answers obtained during interviews conducted with LCA/environmental experts from companies and academia, the main requirements of LCA were identified and separated in three aspects (Environmental, Economic and Social), as shown on table 12.

Table 12: LCA requirements from stakeholders in Brazil and Spain.

	ASPECTS		
REQUIREMENTS	**ENVIRONMENTAL**	**ECONOMIC**	**SOCIAL**
Different LCA software	x		
Units data	x		
Indicators	x		
Quality of data base	x		
Allocation	x		
Data sensitivity	x		
Availability of data	x	x	x
Confidentiality	x	x	
Boundaries	x		
Limitations	x	x	
LCA results	x	x	x
Interpretation	x	x	x
Marketing	x	x	x
Legal obligations	x		x
Internal sustainable policy	x	x	
Customer restrictions		x	
Sharing information	x		x
Fear of share data	x	x	x
Scientific contribution	x	x	x
Communication	x	x	x
Stakeholders			x
Internal relationship			x
External relationship			x

LCA experts identified requirements, problems and barriers according to their experience. The next step in this research is mapping the environmental information flow from the LCA stakeholders using the Social Network Analysis method, which will be explained later.

2.3 - Social Network Analysis (SNA)

The consideration of the stakeholder influences on LCA studies is very important for this research, and for this reason a Social Network Analysis of the experts in this field in Brazil and Spain is included, and its results are discussed on Chapter 5 of this thesis.

2.3.1 - Social Networking (SN)

Social scientists use concepts and categories associated with network analysis to the study of various subjects (Gould, 1993; Hanneman & Riddle, 2005). These categories and concepts are applied to identify the structures that emerge from various forms of relationships between different actors (Berkowitz, 1982; Pretty, 1995; Molina, 2001; Valente, 2010; Ugander et al., 2012).

The social network analysis includes a specific set of methods and techniques that support and document their relationships (Sanz, 2003; Pretty & Smith, 2004; Smith, 2011). It can document and communicate how a society works (Borgatti & Everett, 1999; Boutilier, 2008). SNA's techniques include widely developed statistical models to simulate complex situations in order to support decision-making processes (Snijders, 2010) (Figure 13).

Pretty and Ward (2001) state that all links established between the various actors in social networks are the source for social capital creation. Social capital is understood as the relations of trust, reciprocity and exchange, rules, standards and common sanctions, and the connection between networks and groups.

To analyse and make good use of the knowledge related to the behaviour of social networks, it is important to identify actors or stakeholders and their relationships, and above all, to apply scientific assessment methods (King, 2000). A qualitative assessment may not be enough to understand social processes, yet it is an essential component, as Velazquez and Gallegos (2005) establish.

From this point of view, Social Network Analysis should be undertaken at the very beginning of a development intervention to set the framework for subsequent participatory efforts. As such, Social Network Analysis can contribute to the development of participatory approaches, in particular environmental studies.

Regarding this research, the stakeholder analysis addresses the fundamental questions of:

(1) Who are the key stakeholders in the undertaken or proposed study?
(2) What are the main requirements of these stakeholders?
(3) How will they be affected by the study or project?
(4) How much influence do the different stakeholders have (primary/secondary)?
(5) Which stakeholders are most important for the success of the project (if any)?

Within the framework of Social Network Analysis, a stakeholder analysis can contribute to a deeper understanding of the environmental and institutional context. When undertaken prior to other participatory endeavours, the stakeholder analysis can be fundamental to develop a participation strategy, including the identification of appropriate approaches to involve the different stakeholders, influence on them, and convey the environmental study importance.

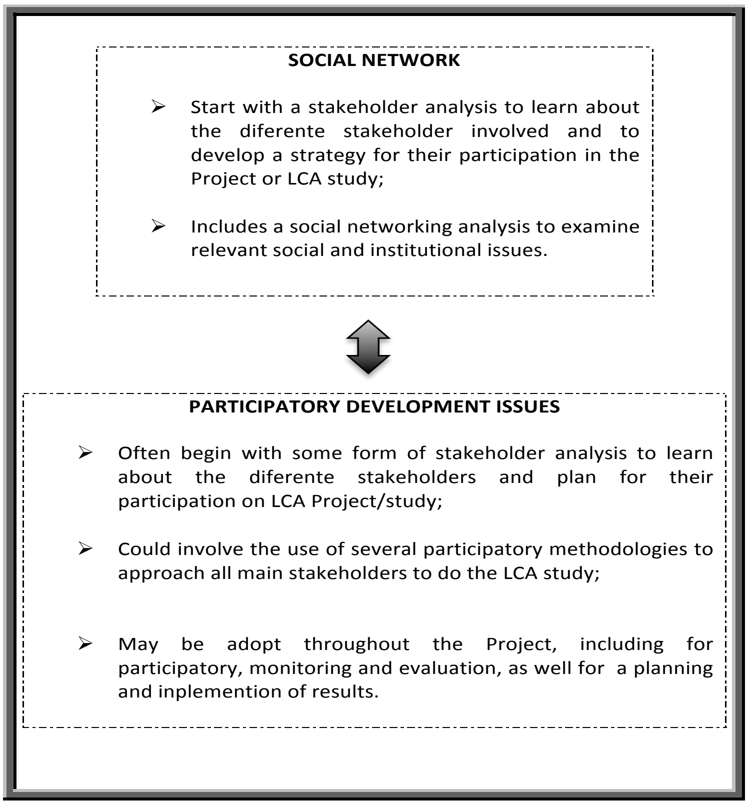


Figure 13: Social Network and participation linkages.

2.3.2 - Social Networking: Contents

To Lozares (1996), the content of a social network is a relational matter or substance (such as affection, information or property). It flows through units (nodes) in the network, through relationships (flows) established between them upon the exchange of such content.

In this thesis, an LCA performed through the analysis of availability of different types of inventory information for stakeholders is described. This includes those doing the LCA, the respondents, the delivery of these databases, and those who study the information, as well as requirements and concerns about security and knowledge exchange.

2.3.3 - Social Networking: Topology

The topology of social networks is a graphical representation of actors and their relationships, and describes the way in which nodes are connected.

According to Baran (1964) there are three basic network topologies, which are presented in Figure 14.

The types of networks contained in Figure 14 are described below.

A. Centralized Network: All nodes but one are peripheral and they can only communicate through the central node. The fall of the central node deprives all other nodes of flow.

B. Decentralized Network: There is no single central node but collective central connectors. The fall of one of the central nodes involves disconnecting one or more nodes of the whole network. The fall of the central cluster necessarily produces rupture and practical disappearance of the network.

C. Distributed network: All nodes connect to each other without having to necessarily pass one or more local centres. In such networks the centre-periphery division disappears and, therefore, there is no filtering power on the information flowing through it.

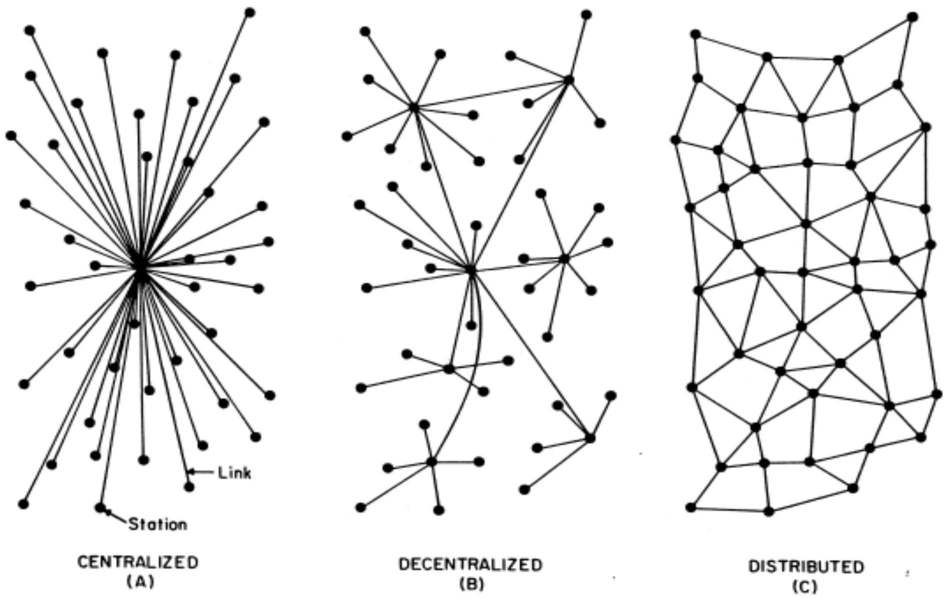


Figure 14: Centralized, Decentralized and Distributed social Networks (From Baran, 1964).

2.3.4 - Social Networking: Relationship

According to Alba (1982), relationships can be formal in the institutional sense; informal; permanent or temporary; in process or consummated; directional or not; shallow or deep; conscious or unconscious. Everything depends on the nature of the problem under study.

Given its complexity, Mitchell (1973), Mitchell et al., (1997) as well as Tichy & Fombrunc (1979) suggest focusing the study on one or some of these relationships but not all of them, in order to be able to study existing links and exchanges with the necessary formality and depth.

Therefore, in this thesis the formal and informal relationships, information exchange and requirements in relation to the achievement of the LCA study objectives by different interest groups in Brazil and Spain are addressed.

2.3.5 - Estimating relative rates and network structure

In social network analysis, it is important to use indicators in order to evaluate network characteristics and nodes behaviour as objectively as possible.

According to Freeman (1979), Hanneman (2001) and Velázquez & Gallegos (2005), there are useful indicators for social network analysis. These indicators can be determined individually (for each node) or collectively (for the whole network, or for node groups).

All rates listed in Table 13 and the network graphical representation can be calculated using the UCINET 6.181 software (Borgati et al., 2003).

Lozares (1996) conceptualized the shape of a social network as the abstract expression of the relationships between its nodes and the properties of global settings or some parties, that is, what is often described as guidelines, model or structure network.

Table 13: Indicators on social networking. (Source: based on Velásquez and Gallegos (2005)).

INDICATOR	DESCRIPTION	NODE APLICATION	NETWORK APLICATION
Density	It shows the percentage value of	Yes	Yes

	the network density. It is a measure expressed as a percentage ratio between the number of relationships with potential relationships		
Centrality Degree	Number of actors to which an actor (node) is directly attached.	Yes	No
Centralization Index	Special condition in which an actor has a clear centre to be highly connected to the network role.	No	Yes
Betweenness	Ability of a node to mediate communications between pairs of nodes.	Yes	Yes
Closenness	Ability of an actor to reach all network nodes.	Yes	Yes

Density is defined as the ratio of de facto relationships to potential relationships. In other words, density shows the network connectivity rate.

Centrality Degree is the number of actors to which an actor is directly linked, and is divided in two levels: the level of output or out degree (sum of relations that an actor have to the rest) and Grade Entry or in degree (sum of relations referring to an author by others).

Centralization Index is a special condition in which an actor has a clear centre to be connected to all nodes, so he needs to go through the hub to connect with others.

Betweenness focuses on communication control by the nodes, and it is interpreted as the ability of a node or actor to mediate communications between pairs of nodes. This analysis considered all possible geodesic paths, which are the shortest routes that an actor must follow to reach other nodes.

Closenness is the ability of a node to reach all players in a network, and it is calculated by measuring the geodesic distances from one actor to others. Note that this method can only be used for symmetric matrices, i.e. actors with mutual influence, with a high level of closeness that is interpreted as the nodes' better ability to connect with other players in the network.

According to Sanz (2003), depending on what the network analysis determine, the study of the above mentioned indices can focus on centrality differences, on the strongly connected clusters, in structurally equivalent positions or in unique positions.

2.3.6 - Advantages and disadvantages of SNA

Conceptualization of reporting relationships between actors as graphs easy to understand and with simple vocabulary is among the advantages of using SNA.

Also, SNA methodology includes analytical tools that can be used to define many social structures' characteristics, and provides mathematical calculations to analyse and measure these properties, for which it has diagramming tools and easy to use calculation tools.

Disadvantages of this method are based on the information provided by stakeholders on their links and relationships, which may not be entirely accurate, due to respondents' intentional or unintentional omissions.

2.3.7 - Social Network Analysis of LCA stakeholders

In the management of products, processes or services' environmental issues, the stakeholder analysis is vital to improve their solution. Therefore, to achieve efficient management in which various interest groups are involved, it is also important to study the relationships between them and their information flows. All this is based on the analysis of social networks and in this case, management of Life Cycle Assessment studies is proposed in order to improve the information flow, based on LCA experts and stakeholders' experience and requirements differences.

Production process environmental problems are frequently related to domestic issues such as technology, efficient management and external legal and market conditions of each region or country. This implies the existence of different actors additional to decision makers that have to be considered in the participatory management of production process or research projects.
Having knowledge about the existing social networks and the actors that are part of those networks, will allow learning not only about who is directly or indirectly linked to management in this area, but also to understand the structural condition of their actions as well as their links or relationships with other stakeholders. According to Sanz (2003), SNA contributes to a description of the situation "as is" and allows to predict network behaviour and help its management.

2.4 - Life Cycle Assessment oriented to the Agri-food industry (Phase 2)

2.4.1 - Introduction to the Agri-food industry

The Agri-food industry evolution and the quality standards stablished by industrialised countries are predominantly driven by the acceleration of regulatory requirements responding to consumers and governments concerns about food safety and quality, as well as cientific developments regarding risks associated with food. Currently, the Agri-food sector is increasingly pervaded by an abundance of private food safety and quality standards, which operate parallel to regulatory systems and are not legally mandatory in a regulatory sense.

These private standards have arisen in response to regulatory developments and, more directly, to consumer concerns and they are regarded as a means of market competitive positioning for high-value agricultural and food products. They represent an indication of how the agricultural and manfacturing production have been evolving worldwide (Henson & Hooker, 2001). Furthermore, this phenomenon is well-established in industrialised countries (not only in the context of international trade) and also within developing countries Agri-food markets (Reardon et al., 2001; Reardon & Berdeguer, 2002).
The Agri-food sector experienced huge changes along the last century. Food production was progressively subjected to industrial parameters and consumption patterns and evolved towards new dietary habits and the convenience food phenomenon arising in different countries. Several economic, political and social factors explain this evolution, but to a higher extent, the development of scientific and technological knowledge is the main factor behind the changing profile of the Agri-food industry (Goodman et al., 1987). Three key stages in the development of scientific and technological knowledge explain the main trajectories taken, overall, by the traditional Agri-food industry, to achieve the actual modern configuration of the food industry:

1) mechanization due to the Industrial Revolution;
2) extensive use of chemical fertilizers and pesticides due to the Green Revolution; and,
3) the emerging trend of genetic engineering linked to the development of biotechnologies.

This industry sector has gone through an intensive development process which has resulted in major structural changes, not only in the sector itself, but also in its relation to the agricultural system, to natural resources and to manufacturing facilities (Duarte et al., 2015).

The food industry also faces specific challenges in the sustainability context for three reasons (Hartmann, 2011):

1- Production requirements of raw materials, as well as environmental, economic and social conditions along the whole value and supply chain,
2- Its strong impact and heavy dependence on raw materials and human resources (Genier et al., 2009; GfK et al., 2009); and
3- Quality, healthiness and safety of products; the multifaceted structure of the entire food chain (Maloni & Brown, 2006).

2.4.2 - Stakeholders of the Agri-food industry

In the context of sustainability, reports have acted as an essential communication tool between organisations, the Agri-food sector and their stakeholders, and their focus on environmental and social performance (Mori Junior, 2014). In a study by Sustainability and UNEP (1998), the reasons for reporting are: "to enhance the ability to track progress against specific targets; to facilitate the implementation of the environmental strategy; to achieve awareness of environmental issues throughout the organisation; to acquire the ability to clearly communicate the corporate message; to achieve greater transparency to improve credibility; to develop the ability to convey efforts and standards; to adquire licences to operate and campaign; for reputational benefits; to identify cost savings; for increased efficiency; to obtain enhanced business development opportunities" (Kolk, 2004; Kolk, 2010).

Neutralising threats or exploiting opportunities due to public concerns requires a comprehensive approach to sustainability by addressing the environmental and social issues that are relevant for stakeholders, and by suitably communicating them (Piacentini et al., 2000; Heikkurinen & Forsman-Hugg, 2011). In this context, LCA studies and sustainability reports have acted as an essential communication tool between organisations and their stakeholders, and focus on environmental and social performance (Mori Junior, 2014).

2.4.3 - Literature review of Life Cycle Assessment studies in the Agri-food industry

Observing the studies and publications from the last decades, scientific studies, including LCA works have shown that most food and supply chains are not sustainable because of the environmental impacts occurring in different phases of their life cycle.

The Strategic Research Agenda 2006–2020 of the European Technology Platform Food for Life has defined sustainable food production as the most important challenge faced by the European food industry. In an effort undertaken by many European countries, the use of sustainability tools and life cycle assessment (LCA) have been applied for more than 20 years in Agri-food industry systems to support environmental decision-making via the identification of the environmental impacts throughout the systems' life cycles. In Europe's case, the ENVIFOOD protocol was created to connect international institutions and agencies to assess and improve the use of environmental methodological applications in the Agri-food industry. The Food and Agricultural Organisation (FAO) predicts that the world's population will increase to 9.7 billion people by 2050. To support this, the FAO also predicts that the overall food production requirements will need to increase by almost 50 percent from the production levels (FAO, 2017).

ENVIFOOD is a European Protocol, implemented by the European Food Sustainable Consumption and Production Round Table (**EU Food SCP RT**), in line with the PEF Guide and represents a starting-point for developing PEFCRs among the food and beverage product category.

The European Food SCP RT was initiated in 2009 as an initiative co-chaired by the European Commission together with other partners from the food supply chain and supported by the UN Environment Programme (UNEP) and the European Environment Agency (EEA).

This program is based on a harmonised life cycle approach with the objective of allowing an open and results driven communication among all the stakeholders along the food chain. This initiative, aims to promote a coherent way of assessing and communicating, on a voluntary basis, the environmental performance (environmental database) of Agri-food products, constituting the foundation from which to develop a harmonised framework methodology (ENVIFOOD Protocol).

The environmental impact produced by the Agri-food industry is known internationally and for this reason the EU created the ENVIFOOD Protocol, which is an initiative co-chaired by the European Commission and partners from the food supply chain (De Camillis et al., 2012).

It aims at establishing the food chain as a major contributor to sustainable consumption and production in Europe, representing the first developed sectorial and science based methodology for assessing the environmental performance of Agri-food products in Europe along their life cycle. In this context, ENVIFOOD could serve as a starting point for developing:

- Requirements, criteria, tools, datasets and assessments;
- PEFCRs for food and food packaging by defining several product categories and related PEFCRs under Protocol ENVIFOOD level; and
- Communication methods; creation of product group/sub-group specific rules (PCRs).

ENVIFOOD protocol was developed by the Working Group 1 of the European Food SCP RT following a stepwise procedure, in accordance with EU legislation and they took into consideration:

- The International Reference Life Cycle Data System (ILCD) Handbook;
- The Commission's Product Environmental Footprint (PEF) Guide;
- All the existing and upcoming international standards on LCA, environmental labels/declarations, and eco-design (ISO 14040/44; ISO 14067:2013); and
- Other emerging methodologies/guidelines; critical review of environmental assessment case studies or data availability and requirements (Masoni et al., 2012).

In this research, through a review of international initiatives of LCA in the Agri-food sector, a special focus is placed on two relevant and recent European initiatives, which highlight government commitment towards the use of best practices and technologies in production and to achieve through education a better consumption and eco-labelling harmonisation and assisting. As far as eco-labels/declarations and footprints are concerned, only the most important ones are reported in this thesis.

To governments, other institutions and stakeholders in the supply chain, auditing plays a fundamental role in the development and consolidation of the LCA methodology as an essential tool for the assessment of Agri-food products' environmental performance. This aspect is highlighted in this review, which reports some of the most important LCA initiatives developed by agricultural and livestock operators, the industry, logistic and trading sectors, packaging and/or food waste operators; as well as other important variables to be considered at the end of the life cycle of products and processes from the Agri-food industry.

It is important to mention that one of the key issues for the Agri-food sector is the lack of reliable and up-to-date inventory data on agricultural and manufacturing food products and processes for developing not only accurate LCA studies but also for hotspot analysis, communication, and further labelling. The same situation could be found in other sectors, and consequently there is a growing need for comprehensive, clear, well-documented, and consistent data in order to increase the accuracy and comparability of LCA studies. From this perspective, scientific articles comparing 70 studies of LCA in the Agri-food industry have been analysed and will be reported and highlighted in the next section.

Chapter 3

Goals and Hypothesis

3 – Goals and hypothesis

General objectives:

The general objective of the present thesis is the definition of an improvement roadmap and the proposition of a good practices manual to improve and facilitate LCA studies in the Agri-food industry. The objective of this research is twofold: 1) people and process assessment of the requirement differences of LCA's experts in Brazil and Spain, and 2) quality and quantity information assessment in LCA studies in the Agri-food sector.

Specific objectives and hypothesis:

The research focus regarding people and process assessment is to identify differences on barriers/problems and phases of LCA's studies in Brazil and Spain, as well as the identification of information nodes, the assessment of relationships among actors and the analysis about how they exchange information. Thus, the specific objectives to improve LCA studies related to people and process assessment are:

Objective 1 – To describe and classify data sharing requirements to perform stakeholders LCA in Brazil and Spain.

Hypothesis 1: There are significant differences in the requirements of data exchange and the communication process between stakeholders in Brazil and Spain.

Objective 2 - To understand and map the environmental information exchange in Brazil and Spain.

Hypothesis 2.1: The Social Network Analysis (SNA) will allow identifying the main stakeholders and the links between them to improve people and process management.

Hypothesis 2.2: The Social Network Analysis (SNA) will be different between countries.

The research aim regarding quality and quantity of environmental information assessment is to analyse scientific information from LCAs in the Agri-food sector, as well as to identify the appropriate variables to assess the performance and reliability of LCA studies in this field. Thus, the specific objectives to improve LCA studies related to quality and quantity of environmental information in the Agri-food industry are:

Objective 3 – Identifying and selecting the main variables that can be used to evaluate LCA quality and elaborating a checklist.

Hypothesis 3: There is a minimum number of variables to evaluate and measure the quality of LCAs.

Objective 4 - Evaluating current literature in the Agri-food sector according to the previously elaborated checklist.

Hypothesis 4: The variables selected for the checklist will allow researchers to evaluate LCA studies performance.

Objective 5 - Analyzing possible correlations or dependences between selected variables.

Hypothesis 5: The selected variables could be correlated showing some dependence among them.

Objective 6 – Defining an objective index to measure the amount of information included in the analyzed LCAs.

Hypothesis 6: The amount of information contained in an LCA can be measured in an objective way.

Objective 7 - Measuring the entropy of the data used to perform an LCA.

Hypothesis 7: The degree of entropy will differ between LCAs.

Objective 8 - Testing if the objective index used to measure the information quantity included in LCAs shows statistically significant differences among groups of LCAs made from the categorical selected variables.

Hypothesis 8: There will be statistically significant differences among groups of LCA works in the objective index selected to study the amount of information enclosed in them.

Objective 9 - Grouping the different LCAs according to similarities and differences in the measured variables.

Hypothesis 9: Depending on the selected variables and the amount and heterogeneity of information contained in the LCAs, the different LCAs can be classified in groups with similar patterns among them and different from those of the other groups.

Objective 10 - Establishing an improvement roadmap for each LCA group, for the short, medium and long term.

Hypothesis 10: The similarity between LCAs belonging to the different groups will allow the definition of a specific improvements roadmap.

Objective 11 - Obtaining a Manual of Good Practices and a threshold of the amount of information needed to perform an LCA in the Agri-food industry with a minimum quality level.

Hypothesis 11: The analysis carried out in the thesis will allow elaborating a Manual of Good Practices, as well as setting an information index threshold, which can be a useful guide in the correct accomplishment of LCA in the Agri-food industry.

Chapter 4

Methodology

4 – Methodology

4.1 - General research strategy

Studying experts' own experience using certain methods and tools is a means to acquire knowledge and to determine the state of the art in a given field. In order to investigate current requirements and search for improvements in LCA applications, the following two approaches have been used:

- Direct approach, by asking LCA experts (users and developers) what requirements they have to address, and about methods, tools applications and data management.
- Indirect approach, by analysing LCA published works in the Agri-food sector in order to determine the state of the art of LCA actual applications.

In this line, this thesis is divided into three main phases:

1) Qualitative analyses to assess LCA data exchange requirements, stakeholders' relationships and differences between LCA's experts in Brazil and Spain belonging to both academy and industry fields: **People and process assessment.**

This phase intends to identify barriers/problems that experts in LCA find in Brazil and Spain. It includes the analysis on how experts exchange information and a social network analysis to evaluate experts' relationship.

2) Quantitative assessment of the information used to perform LCA in the Agri-food sector: **Information analysis and metrics**.

This phase aims to assess the amount of information used in LCA studies in the Agri-food sector, as well as to identify the appropriate variables to assess the performance and reliability achieved by such LCA studies.

3) Design of a good practices manual and a roadmap to improve LCA performance in the Agri-food sector: LCA good practices in the Agri-food sector**.**

This phase is the downstream results proposition of previous phases. The objective is to develop an initial version of a practical and applicable tool to guide users when it comes to perform LCA in the Agri-food sector in a more convenient and standardized way.

4.2 - Research methodology

The methodology of this thesis is divided into 3 phases, as shown on Figure 15.

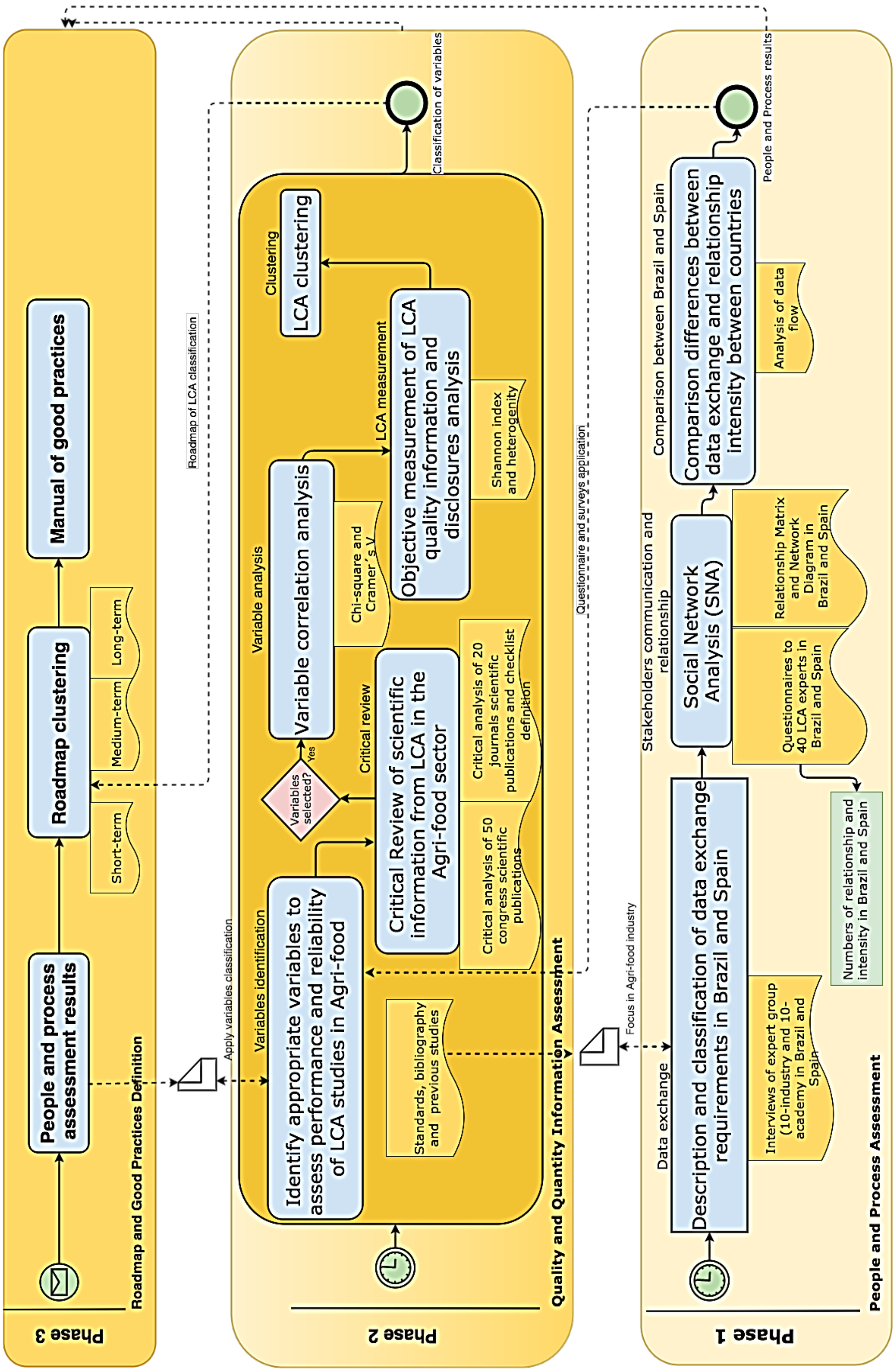


Figure 15: Flowchart of all phases of the thesis.

4.2.1 - Phase 1 - People and process assessment.

Three steps were carried out to analyse how LCA stakeholders are communicating and exchanging information in Brazil and Spain: Data exchange analysis, Stakeholders communication and relationship analysis, and Comparison between Brazil and Spain, as shown on Figure 16.

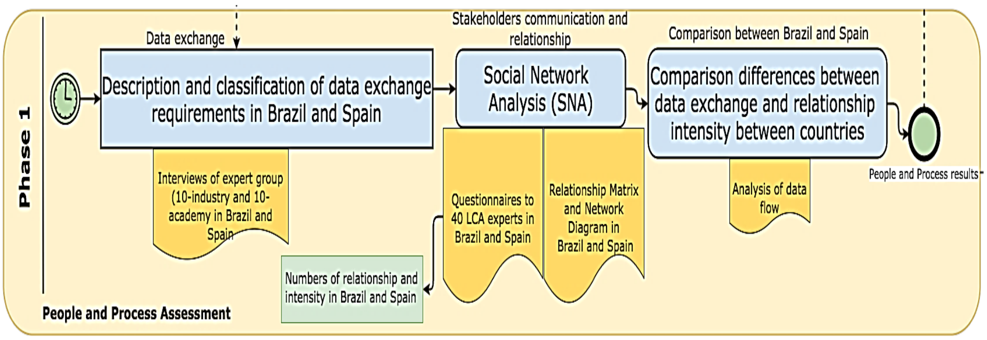


Figure 16: Interview, survey and Social Network Analysis.

4.2.1.1 - Data exchange

This step can be defined as an exploratory study with a qualitative evaluation of requirements of LCA practitioners in Brazil and Spain. This phase is divided into four steps: 1- Experts selection; 2- Interview guide development; 3- Experts interviewing, and 4- Analysis of information. The data exchange analysis was conducted between September 2014 and April 2015.

4.2.1.1.1 - Experts selection

Three kinds of institutions were considered when interviewing LCA experts: companies, universities and research centers. An important consideration in the selection of institutions was that they offered the possibility to interview two or three people working on different areas within the same organization. This fact allowed analyzing LCA form different points of view.

40 LCA experts linked to the Brazilian and Spanish academia and industry were selected. Specifically, 20 experts from each country, 10 from industry and 10 from academy were selected. The Snowball sampling method was applied to obtain more respondents. Experts from academia notoriously involved with LCA in Brazil and Spain were selected to act as a reasonable seed of the snowball sampling method.

The selection criteria of initial experts belonging to academia (universities and research centers) were as follows:

- Quantity of publications about Life Cycle Assessment.
- International prestige.
- Numbers of supervised thesis (MSc and PhD).

The selection criteria of initial experts belonging to industry were as follows:

- Earlier experience applying LCA in companies.
- Participation in governmental conferences and private meetings about LCA.

4.2.1.1.2 - Interview guide development

An interview guide was developed to set the same key points to be addressed with experts of the different sectors. Key points were set considering both theoretical and practical issues related to LCA practice. The same structured interview was used regardless of the origin of the expert (academic or industrial) so that results could be compared.

The guide was divided into different subjects, for which different questions were developed, as shown on Table 14. The key points to be addressed for this evaluation were: general LCA expert relationships, main stakeholders in LCA, main information sources, difficulties with the LCI, requirements for data quality, sharing information, restrictions and problems in sharing information and confidentiality of data and results. Different conceivable answers to the questions were tested in order to verify that nothing relevant was forgotten. As a final review, the guide was previously tested with potential interviewees with similar backgrounds, i.e. LCA consultants and professionals.

Table 14: List of key points to set the interview guide.

	KEY POINTS	GUIDE OF INTERVIEW ISSUES
1	What is your relationship with LCA and how could you describe your main actuation area or areas?	Expert role
2	Which are your main partners when conducting a LCA (contacts, people involved, etc.)?	Identification of stakeholders
3	What are you main information sources (individuals, organizations, companies, etc.) when performing a LCA?	Diversity of sources of information
4	Which difficulties did you have during the data acquisition phase for the LCI?	Difficulties in getting data
5	Which are the main requirements when considering data quality?	Identifying when data is suitable for the experts
6	Which LCA information (data or results) is shared during and/or after the study?	Data exchange
7	Which restrictions and problems have you found when sharing LCA information (data and results)? Were there any problems related to data sharing? Have you ever experienced restriction or other problems regarding sharing LCA results, such as results or inventory data? What were these problems?	Sorting information to data sharing in LCA studies
8	Have you ever experienced problems regarding information confidentiality? In this case, how have you handled this situation?	Identifying how confidential information is handled in a LCA analysis

4.2.1.1.3 - Experts interviews

The structured interview was held with LCA experts in Brazil and Spain, divided in two focus groups:

1. Experts from Academy and research centers (LCA developers)
2. Experts from industry (LCA users)

The objective is to identify differences (if any) in people and process requirements to perform LCA studies between these two groups of experts, as well as between countries. In each country, 20 interviews were conducted using the structured interview (see Table 14), ten in each focus group.

Before the interviews, the interviewees were given a brief presentation of the study background. All interviewees were individually interviewed for approximately 30 minutes. Interviews were recorded after obtaining experts' consent.

4.2.1.1.4 - Information analysis

All interviews were fully transcribed to be analysed in detail. The data was analyzed using content analysis with ATLAS.ti software®. This software is commonly used for qualitative research data processing by making use of content analysis. There are some important features in content analysis that distinguish it from other methodologies: it recognizes the importance of language; it is replicable and applicable, it is analytically flexible and, when properly conducted, it is a methodology that can be checked for its accuracy, reliability and validity (Duriáu et al., 2007; Krippendorf, 2004).

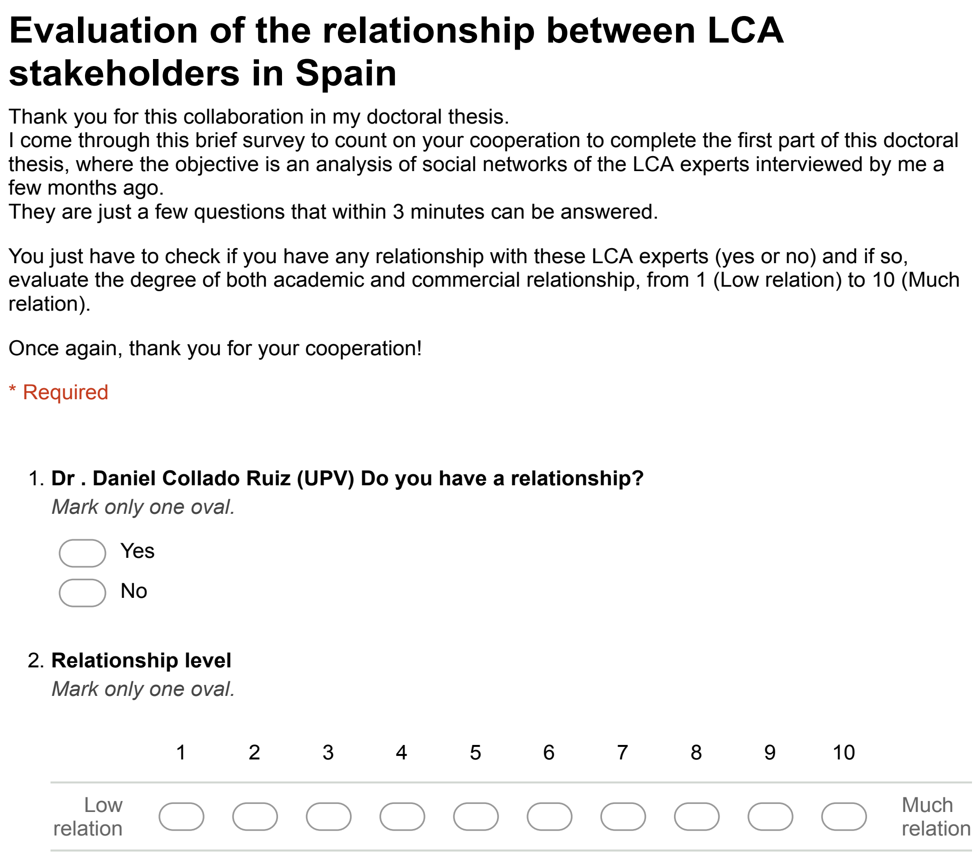
When relationships and patterns that emerged during the interview became clear to the interviewer, categories and sub-categories were defined to classify experts' responses. Once interviews transcriptions were completed, the final categories that represent the main information were selected to be graphically analysed through the ATLAS.ti® software, which automatically managed the number of words and categories previously defined. After the analysis of categories the results were graphically depicted using the Excel software.

4.2.2 - Social Network Analysis (SNA): Stakeholders communication and relationship assessment

This step is aimed at evaluating the social network relationships of LCA stakeholders. It was divided into four steps: 1- Survey to the same 40 interviewed LCA experts in Brazil and Spain; 2- **Experts' relationships matrix generation**, **Graphical representation of results**, **and 4- Comparison between Brazil and Spain**.

4.2.2.1 - Surveys

After interviewing 40 LCA experts in Brazil and Spain, a survey was designed to know both the number of connections among experts and the intensity of relationships among them in each country. A questionnaire was designed and sent separately to each of all 20 LCA experts in Brazil and in Spain. Experts were asked to select other experts they were related to or they interacted with, pointing out the intensity of the relationships they had with their contacts in a ten-point Likert scale (from 1, the lower intensity, to 10, the higher), as can be seen in Figure 17. The open source Google Forms® tool was used to perform the survey between April 2016 and June 2016.



Evaluation of the relationship between LCA stakeholders in Spain

Thank you for this collaboration in my doctoral thesis.
I come through this brief survey to count on your cooperation to complete the first part of this doctoral thesis, where the objective is an analysis of social networks of the LCA experts interviewed by me a few months ago.
They are just a few questions that within 3 minutes can be answered.

You just have to check if you have any relationship with these LCA experts (yes or no) and if so, evaluate the degree of both academic and commercial relationship, from 1 (Low relation) to 10 (Much relation).

Once again, thank you for your cooperation!

* Required

1. **Dr . Daniel Collado Ruiz (UPV) Do you have a relationship?**
Mark only one oval.
Yes
No

2. **Relationship level**
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low relation											Much relation

Figure 17: Survey questions. (The Figure shows the exact question responded by experts in Spain using Google Forms® tool).

4.2.2.2 – Experts’ relationships matrix generation

The number of connections and their intensities were collected to create the relationship matrix. Experts’ names were listed in both rows and columns building a square matrix. Based on the information collected in the survey, when there was a relationship between experts it was codified putting the number 1 in the corresponding cell of the matrix, as shown on Table 15. To do that, the UCINET® 6.181 software was used (Borgati et al, 2002). This software is designed for Windows and is one of the most widely distributed computing tools in SNA, comprising a package of tools that fulfil different and complementary roles. Moreover, to codify the intensity of the relationship between experts the number of the selected ten-point Likert scale was registered in the matrix, as shown on Table 16.

Table 15: General matrix used to SNA in Spain.

	Daniel	Salvador	Maria	Clara	Francesc	Gabriela	Jesus	Raúl	Joan	Jorge	Juan	Juan	Leire	Maria	Mercedes	Neus	Neus E	Xavier	Xavier F	Xavier G	Nuria
Daniel Collado Ruiz (UPV)		1	1			1			1						1	1					
Salvador Capuz (UPV)	1		1		1	1			1		1	1			1		1			1	1
Maria José Ceca (UPV)	1	1				1				1	1	1			1	1				1	
Clara Ramírez Sanz (UPV)						1										1	1				
Francesc Tarongi (URV)		1							1			1			1	1		1	1	1	
Gabriela Clemente (UPV)	1	1	1	1					1			1		1	1	1	1				1
Jesus Rieves (Inèdit)								1	1	1		1	1	1	1	1	1	1	1	1	1
Raúl Garcia (Inèdit)							1		1		1	1	1	1		1		1	1	1	
Joan Rieradevall (UAB)	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Jorge Adobon (Itene)			1				1		1		1	1			1				1	1	
Juan Adobon (Itene)		1	1					1	1	1		1	1		1	1			1	1	
Juan Montero (UAB)		1	1		1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	
Leire Barruetabeña (Gaiker)							1	1	1		1	1								1	
Maria Barreiro (Cetaqua)						1	1	1	1			1				1	1	1	1	1	
Mercedes Hortal (Itene)	1	1	1		1	1	1		1	1	1	1					1		1	1	1
Neus Pellicer (UPV)	1		1	1	1	1	1	1	1		1	1		1			1		1	1	1
Neus Escobar (UPV)		1		1	1	1	1		1					1	1	1					
Xavier Boruel (Cetaqua)							1	1	1			1		1					1	1	
Xavier Font (Icta)					1		1	1	1	1	1	1		1	1	1		1		1	1
Xavier Gabarel (UAB)		1	1		1		1	1	1	1	1	1	1	1	1	1		1	1		1
Nuria Rueda		1				1	1		1						1	1			1	1	

Table 16: Example of relationship level described per actor in Brazil based on a ten point Likert scale.

Relationship level	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Aldo Ometto (USP)		4			1	1		1		1
Alex Negueira (USP)	1									4
Ana Danke (USP)	1			1				1		2
Anna Lúcia Mourad (CETEA-ITAL)	2	1	2							3
Jozeti Gatti /CETEA-ITAL)	1							1		1
Daniele Bordalo	1		1							2
Cristiane Leis (USP)					1		1			
Daniele Souza			1							1
Eloisa Garcia (CETEA-ITAL)	1								1	2
Gil Anderi (GP2-USP)				1		1		1		4
Guilherme Moraes dos Santos (BASF)	1			1		1				
Leda Coltro (CETEA-ITAL)			1		1	1		1		3
Marisa Padula (CETEA-ITAL)	1								1	1
Fabien Brone (NATURA)		2	1			1	3			
Rafael Vinas (BASF)		1				1				3
Sueli Oliveira (BASF)	2		1					1		3
Yuki Haminton Kabe (BRASKEM)			1	1	1		2			2
Sebastião Soares (UFSC)	1					2			1	

4.2.2.3 - Graphical representation of results

The last step of this phase consists in graphically representing the stakeholders' relationship of LCA practitioners in Brazil and Spain. Once the relationship matrix was obtained, stakeholders' relationship can be depicted using the UCINET® 6.181 software (Borgati et al, 2002).
To conduct and complement the results, three-core modules of UCINET® 6.181 software were used:

UCINET®. Central program that calculates SNA indicators, the toolbar provides access to other programs. It has a wide range of routines and algorithms calculations and operations on relational matrices, some of which are described below.

Spreadsheet®. Element used to capture the relational data in the form of an adjacency matrix or attributes. It has tools for matrix analysis, prior to the calculation of indicators and chart analysis. The spreadsheet is generally used whenever a need arises to directly change a matrix.

NetDraw®. A graph assumes the role of social networks from the data loaded into UCINET. It is able to handle up to 3.500 information nodes and links.

The graphical representation of stakeholders' relationships is classified in three levels: (1) Centrality - is the number of actors to which an actor is directly linked, (2) Betweenness, which focuses on the control of communications by the nodes, and is interpreted as the ability of a node or actor to mediate communications between pairs of nodes, and (3) Closenesess – which is the ability of a node to reach all actors in a network, and is calculated by counting the distances from one actor to the rest of actors.

4.2.3 - Comparison between Brazil and Spain

This is the last step of the people and process assessment phase where the comparison of data exchange and stakeholders relationships between both countries is made. This comparison was made by observing the graphical results of the previous steps (data exchange, stakeholders' communication and relationship assessment).

4.3 - Phase 2- Quality and quantity of information assessment

To analyze information management, achieved performance and reliability of LCAs published in the Agri-food sector, five steps were carried out: Evaluation variables identification, Critical review of recent LCA publications, Analysis of the independency between variables and Information measurement enclosed in LCA and LCA clustering, as shown in Figure 18.

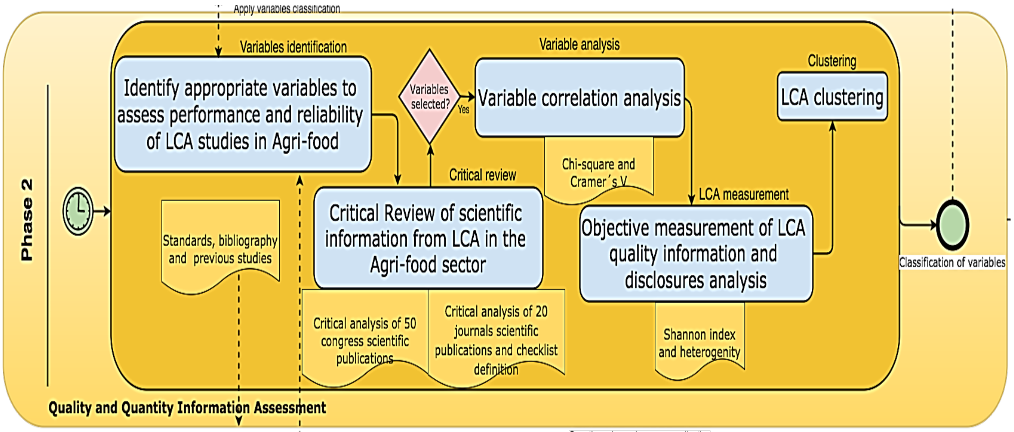


Figure 18: LCA study selection, variables definition and statistical analysis.

4.3.1 - Evaluation variables identification

The objective was to identify the appropriate variables to assess achieved performance and reliability of LCA studies in the Agri-food sector.

To set the variables, the state of the art of LCA was analyzed, as well as LCA standards, and previous studies in this field. An initial set of 25 variables was identified. Three experts in LCA from academy and two experts from industry were selected and a final set of 20 variables were analysed in a focus group session which lasted two hours.
A checklist was elaborated with the selected variables. The checklist will be applied in the next step to complete the critical review of existing LCAs in the Agri-food sector.

4.3.2 - Critical review

The objective was to critically review the information included in an LCA in the Agri-food sector. To do that, 70 published scientific articles on LCA application in the Agri-food sector were selected. Specifically, 50 published scientific articles were selected from the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014). This congress is the most important event of the sector, giving an overview that enables researchers to get information about current industrial LCA applications. To acquire a vision of LCAs applications in a more academic approach, an article sample was completed with 20 scientific articles published in the most recognized journals on this research area in the last 6 years. All papers were analysed using the checklist developed in the previous section.

All articles were selected so that a balanced number of communications focused on three fields: Agro, Food, and Agri-food. The criteria adopted to classify these fields were as follows: when the work was mainly focused on agriculture it was classified as "Agro"; when it was focused on manufacturing it was classified as "Food"; when the LCA boundary is set inside the factory and the impacts come from a mixture of agriculture, manufacturing, consumption and final disposal, they were classified as "Agri-food. The size of sample was defined by statistical significant analysis ($p<0.05$).

4.3.3 - Analysis of independency between variables

To test independency between variables, the Chi-square test was applied, and to know the intensity of the association between variables, when the result of the Chi-square test was significant ($p<0.05$), the Cramer's V statistic was obtained. Statistical analysis was done using SPSS 16.0 for Windows.

4.3.4 - Measurement of information included in LCA studies

The Shannon Index was obtained to measure the amount of information contained in an LCA and its equitability. The information was analised in the Life Cycle Inventory (LCI) phase, where the author gets the input data to assess the impact categories (IC's) representing environmental issues of concern to which LCI results may be assigned.

The quantity of ICs used and the quantity of inputs diversity (compounds) considered to assess each IC was measured for each scientific article. For instance, if the study considered climate change, eutrophication and acidification as ICs, an identification was made of how many compounds were inputed by the author for each IC, for example, in climate change: CH_4, CO_2, CO, N_2O, in human toxicity: No_x,

SO_2, POP, VOC, and in acidification: HNO_3, H_2S, NH_3, SO_3. All data was organized in a matrix to be analyzed using the Shannon Index equation.

The Shannon entropy theory was originally proposed by Shannon (Shannon & Weaver, 1947). In summary, the Shannon entropy method is an approach that considers the uncertainty of variability and riches of data to be analyzed. Shannon developed a measure H which satisfies the following properties for all p_i within an estimated joint probability distribution *P* (Shemshadi, 2011; Zitnick & Kanade, 2004):

a) H is a continuous positive function;

b) If all p_i are equal, *pi*=1/n $p_i = \frac{1}{n}$, then H should be a monotonic increasing function of n; and,

c) For all, $n \geq 2$, $H\ (p_1, p_2, \ldots, p_n) = \mathrm{h}(p_1 + p_2, p_3, \ldots, p_n) + (p_1 + p_2) H(\frac{p1}{p1+p2}, \frac{p2}{p1+p2})$

Shannon showed that the only function which satisfies these properties is:

$$H_{\text{Shannon}} = -\sum^{n} p_{\mathrm{i}} \log(p_{\mathrm{i}})$$

where: $0 \leq p_{\mathrm{i}} \leq 1; \sum^{n}_{\mathrm{j}=1} p_{\mathrm{i}} = 1$

Specifically, in this thesis p_i is computed as the number of compounds taken into account to assess the IC_i divided by the total number of compounds considered in all ICs assessed in a given LCA:

p_i = Number of compounds in IC_i/total number of compounds in all ICs.

Thus, the Shannon index can be seen as the degree of uncertainty associated with the random selection of a component.

Equitability was calculated as:

$$H/H_{max}$$

Where

$$H_{max} = \text{Ln (total number of compounds in all ICs)}$$

High values of equitability mean that a similar number of components has fed the considered ICs.

Finally, the percentiles (P95, P75, P50 and P25) of the Shannon index and equitability sample values were calculated to set the thresholds defining diversity information in the Agri-food sector.

4.3.5 - LCA works clustering

The objective is to classify LCA articles according to the evaluation variables identified in section 4.3.1, grouping communications with similar features which are different from those forming other groups. Cluster analysis finds clusters of LCA articles that are similar in some sense to one another. The articles of a cluster are more similar to each other than they are to articles of other clusters. The objective of the cluster analysis is to find high-quality clusters such that the intercluster similarity is low and the intracluster similarity is high.

To this end, a TwoStep cluster analysis was done to identify homogenous groups based on both categorical and continuous variables (Shannon Index, Equitability) (e.g. Chiu et al., 2011). In the cluster analysis, the Bayesian information criterion (BIC) was applied in the automatic agglomeration method, using the loglikelihood as a distance measure. The importance of the variables in each group was measured by the Chi-square or T-test, setting the confidence level at 95% with Bonferroni adjustment application to numerical variables.

The BIC for several solutions with different numbers of clusters within a specified range was calculated and used to find the initial estimate for the number of clusters. Looking for diversity, the solution with the lowest BIC, easiest to interpret and issuing the greatest number of clusters was chosen. SPSS 16.0 on Windows was used for statistical analysis. All statistical analysis was been selected because was the best way to check our data.
Resulting clusters could be seen as different ways or styles to manage and perform the LCA application, with their inner weaknesses and strengths.

4.4 - Roadmap and good practices definition

The objective is to create a roadmap of practices to be followed when it comes to improve LCA performance in the Agri-food sector. In this sense, the roadmap is

intended to provide experts with insights and guidance in order to increase the quality of their future LCA works in this sector.
Once the number of clusters that classifies LCA applications in the sector and its weaknesses and strengths is known, some practices, methods and tools to improve the LCAs belonging to these clusters could be defined to be applied in the short, medium and long-term. Moreover, defined clusters can be used to classify and group new LCA works. Thus, knowing which cluster a new LCA work belongs to, it is easy to know what steps experts have to take to improve it in the short, medium and long-term. In this context, was proposed the level of quality performance definition to complementing the clustering classification. Beyond the minimum LCA requirements, three suitable levels of LCA application performance were defined according to the selected variables, were Level 1 includes basic variables to consider the LCA application quality as good enough in the Agri-food sector. Level 2 increases the number of items to be considered, including transportation and packaging impacts. In this case, the use of the Shannon index and equitability is a plus to be considered in the study and Level 3 is the most complete and rigorous level, including transportation and packaging impacts, food losses, credit recycling, the Shannon index and equitability.

Finally, **a good practices manual** was written to contribute to the standardization and definition of the minimum requirements to be met when it comes to performing an LCA in the Agri-food sector (Figure 19). The steps to be followed were defined according to the results of people and process assessment (phase 1) and the resulting roadmap after LCA clustering.

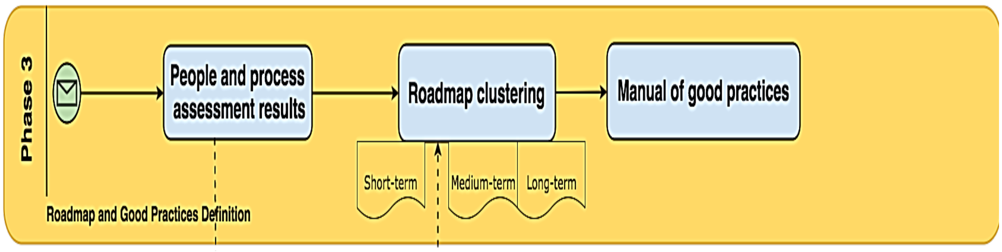


Figure 19: Roadmap and good practices manual.

Chapter 5

Results

5 – Results

In this chapter, the results of this research will be presented. Phase 1, people and process assessment, shows the qualitative analysis and the SNA results in Brazil and Spain. Phase 2, quality and quantity information assessment, shows the results of published scientific articles' critical analysis from the Agri-food sector, including the selected variables and the clustering solution. Finally, the roadmap for each cluster and the general good practices manual will be shown.

5.1 - Interviews with LCA stakeholders in Brazil

The first key points of the Interview guide (20 and 21) targeted the identification of LCA experts' role and their stakeholders' relationships. Figure 20 shows the experts role in the academia and industry fields. All experts were LCA users in both fieds. However, 70% of the academia experts are conducting research to improve LCA methods but only 10% of industry experts work from this perspective. All industry experts have connections with industrial stakeholders, 40% of them have some work connectivity with academics, and only 30% have direct connections with governments (see Figure 21). In the academy, only 30% of experts have direct connections with industrial stakeholders, and all of them interact with academicians, acting as researchers or professors.

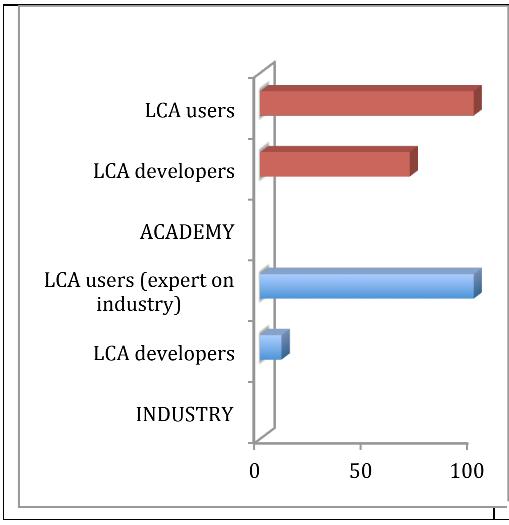


Figure 20: Classification of experts in focus group.

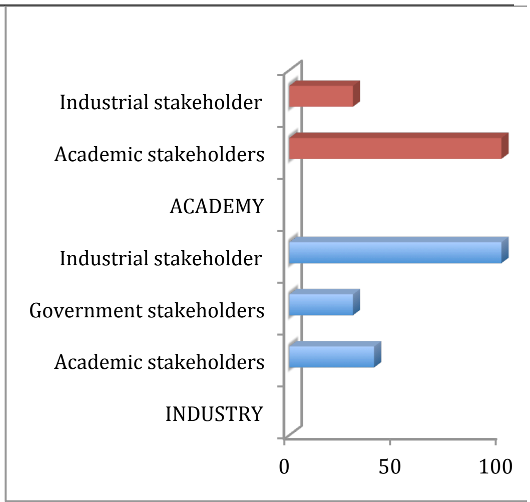


Figure 21: Identification of stakeholders' relationship.

Regarding diversity of information sources, Figure 22 shows how experts develop the environmental data collection to perform LCA studies. All experts from industry get primary data from their company, 90% of them compare their primary data with general databases, most of them using ecoinvent and other databases from LCA software, and 60% of them use scientific literature to suport their studies. Finally, 30% of experts assess the LCI using a database provided by their companies. All experts from academy get data from both scientific and companies' databases. 80% of them use data from a comercial database, mainly Ecoinvent. On the other hand, 70% of this group gets data from other stakeholders, which holds some information that may be useful for the study.

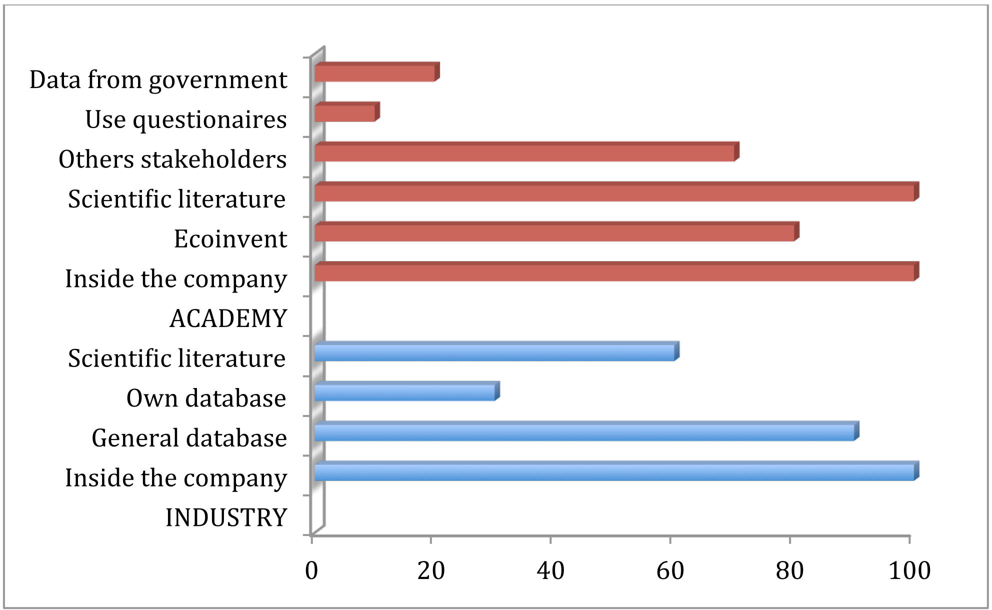


Figure 22: Identification of different sources of data.

Figure 23 shows the main difficulties faced by experts regarding data gathering. All experts from the academia sector said that most of the problems are related to the lack of national databases and the companies' fear to share their data. For 90% of them, difficulties are related to the lack of companies' databases (inventory) and 60% of experts complain because the general database is neither clear nor user friendly.

All experts from the industry sector said that the biggest problem is the lack of systematically measured data gathered by companies. In this line, 90% of experts complain because they find difficulties in geting necessary data from companies' databases. 80% of experts said that both general and internal data are neither standard nor easy to be used and compared. Finally, 40% of industrial experts complain because there are no national databases (Figure 23).

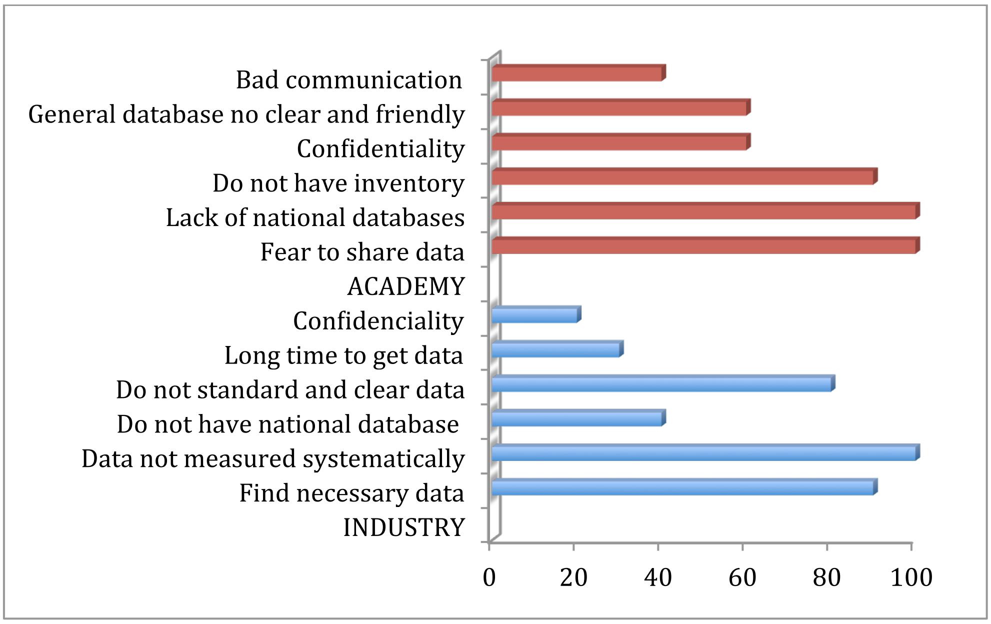


Figure 23: Main difficulties and barriers to get necessary data.

Results about data suitability considerations are depicted in Figure 24. Results show that 90% of academic experts compare primary data with other general databases before accepting data. On the other hand, 80% of academics trust data coming from companies. Regarding data coming from industries, 50% of academics consider the industrial expertise of thecnical staff they interact with as a quality and reliability guarantee of the data exchanged with them. However, 40% of the academic experts consider making a sensitivity analysis as a necesary step to rely on data coherence. Only 30% of experts accept data at face value.

All industry experts stated they compare data with other sources. However, 80% of them accept data at face value. It is worth stating that industry experts (40%) said that the suitability of data "*depends on the goal and scope of the study*".

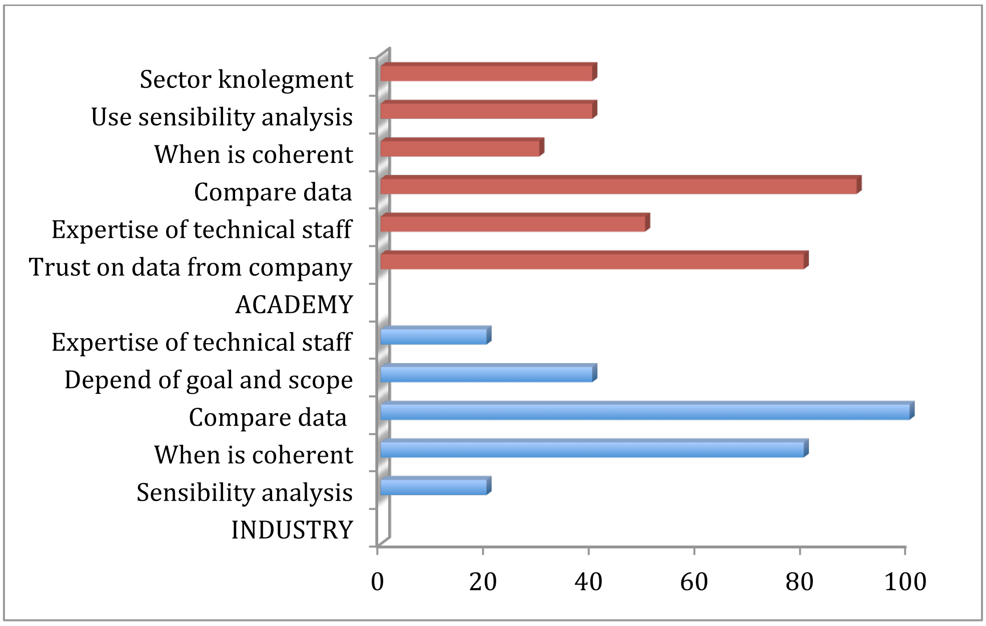


Figure 24: Identification experts consider the data as suitable.

Suitablility results of data to be used and exchanged are depicted in Figure 25. Results show that 90% of industry experts share primary data only inside the company. In this line, all experts consider data as confidential, which hampers data exchange among stakeholders. However, 80% of industrial experts publish some parts of their results, and half of them only publish qualitative results when it is strategic for the company. In this line, 50% of experts publish some selected results on technical reports.

In the academy, all experts try to publish and share their LCA studies results on scientific journals, but showing only general results without specific primary data. In this line, most of the experts publish some part of the results to be used by goverments. Only 50% of experts said that confidenciality is a barrier to publish (Figure 25).

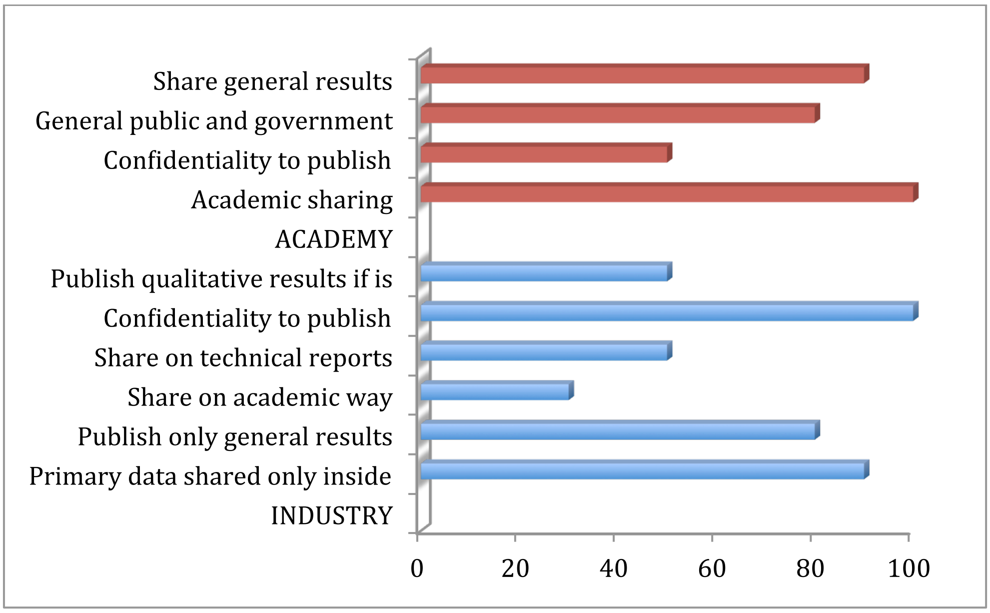


Figure 25: Classification of aspects about sharing information with stakeholders.

Results for the last two questions regarding importance of sorting information to sharing data and how aspects of sharing information is classified and handled by actors are shown in Figure 26. None of the interviewed from academy publish their complete LCA because they worry about consumers misunderstanding results, even when positive results are given. Data confidentiality remains a strong barrier for 90% of them. For all respondents from academia, lack of national databases difficults performing a good LCA. Even when primary data is available, for most respondents from academia this data quality is not good enough. Bad communication between stakeholders is a strong problem for 80% of respondents from academia. On the other hand, in the industry group 60% of experts answered that they have no problems to share data, because once it is decided to publish, they only show general harmonized results. Half of the experts admit that their companies have some fear of sharing their databases. In 50% of the cases they do not compare their results with other similar companies. For 70% of the experts, bad communication with stakeholders difficults carrying out studies. In essence, this question shows that both groups had some kind of problems to share data from industry.

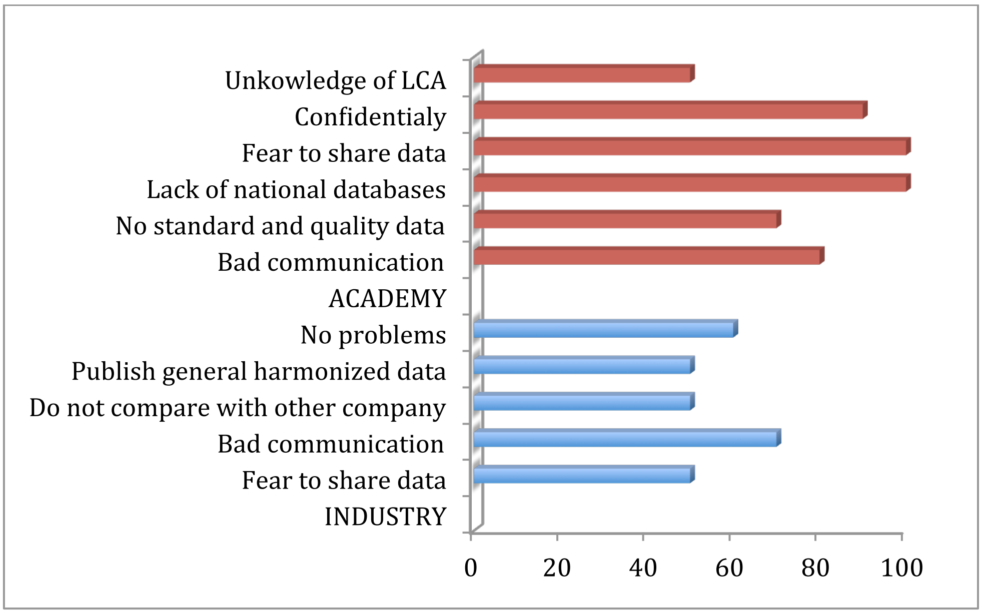


Figure 26: Main data sharing barriers in LCA studies.

Finally, regarding confidentiality none of the experts from both groups claimed to have difficulties using the internal environmental information of companies, because all of them sign a confidentiality agreement with the company which is considered a common practice (see Figure 27). All experts from academia reported that in most studies made for the industry, results are only shown in internal reports. Moreover, companies had control of the publishing process, electing which results can be included and where they should be published. Few experts of this focus group published legal reports.

90% of experts from industry signed a confidentiality agreement, which is a normal practice. For 60% of them all information stays inside the company.

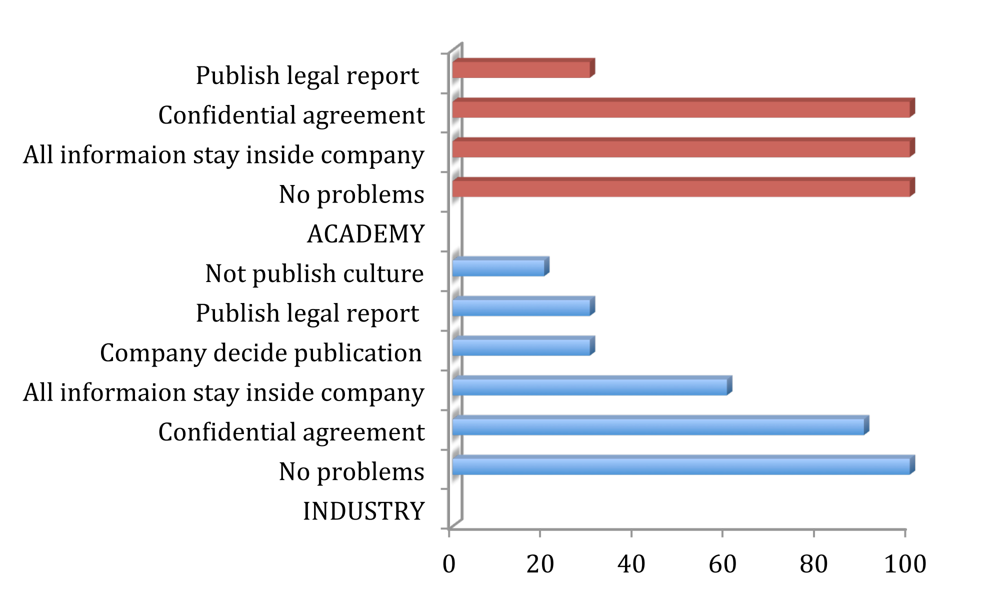


Figure 27:Confidential information in a LCA analysis.

5.1.1 - Surveys and social network analysis of Brazilian LCA stakeholders

Figure 28 shows a graphical representation of the network of actors involved in the use or development of the LCA tool in Brazil. Arrows show the environmental information direction that can be unidirectional or bidirectional. Parts of the network analysis will be shown in later sections in order to clarify relationships between actors.

This graphic presents a sociocentric network with a high degree of graphical density, decentralized, with a medium quantity of links or relationships between the different nodes, and with the presence of isolated nodes. Its conformation is not built on one or few central actors, but by multiple nodes that establish multiple relationships with each other. Some peripheral nodes can only communicate through some nodes (for example private companies or some research groups that perform LCA studies). It could be said that the fall of one of the node centralization would not necessarily lead to the disconnection of one or more nodes of the network as a whole, although their capacity to communication would surely be affected.

The nodes are represented by colors, regrouping the academia actors on the right side and the company actors on the left side to organize them by groups and facilitate their analysis. Actors are represented by Exp.1, Exp.2…Exp.20. The list of experts interviewed can be found in appendix 2.

The network's overall structure and its integration level allow identifying and separating the main components of the LCA database exchange in different Brazilian states.

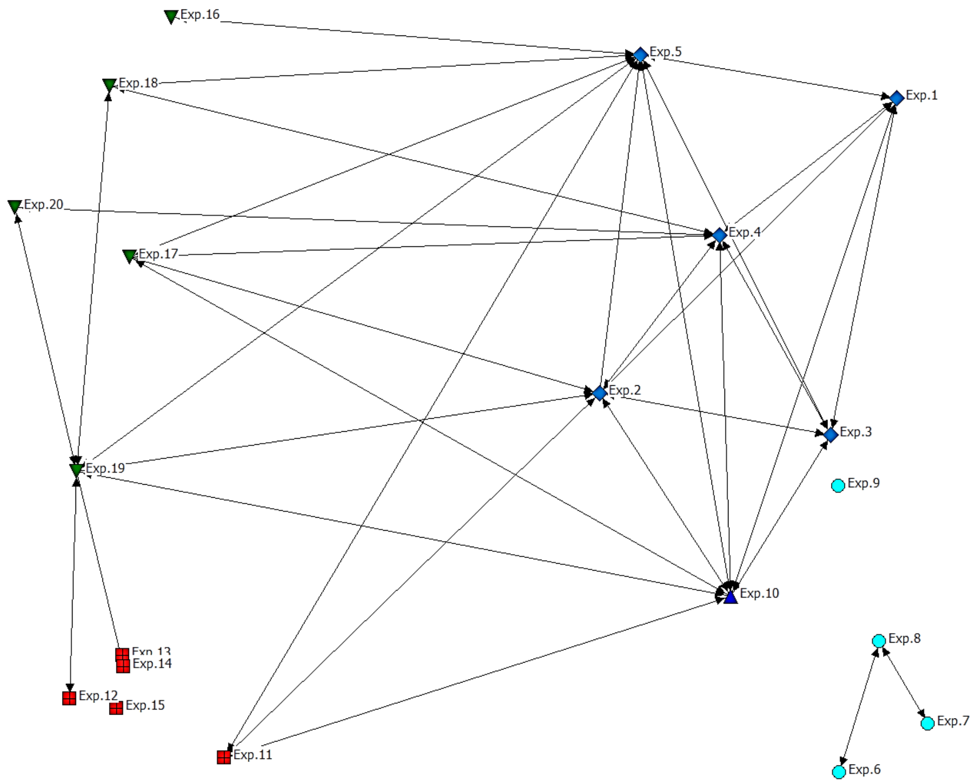


Figure 28: General map of Brazilian LCA stakeholders' connection (Prepared with Ucinet®).

5.1.2 - Centrality degree of LCA stakeholders in Brazil

Figure 29 shows centrality degree values, within the communication network of LCA experts from Brazil. As it can be seen, nodes corresponding to USP, UFSC and BASF actors have higher centrality indexes, that is, a greater degree of communication with other nodes within the network. This result is followed by other companies' reference actors working with LCA in Brazil.

In relation to actors that are more informed (Indegree), universities concentrate the largest sum of relations coming from other actors, see experts 5 and 10, followed by the BASF Company, represented by expert 19.

In relation to which actors inform others more (Outdegree), the greater concentration is also referred to experts 5, 4 and 2 from USP, expert 10 from UFSC, from academy, followed by expert 19 from BASF who represents the industry.

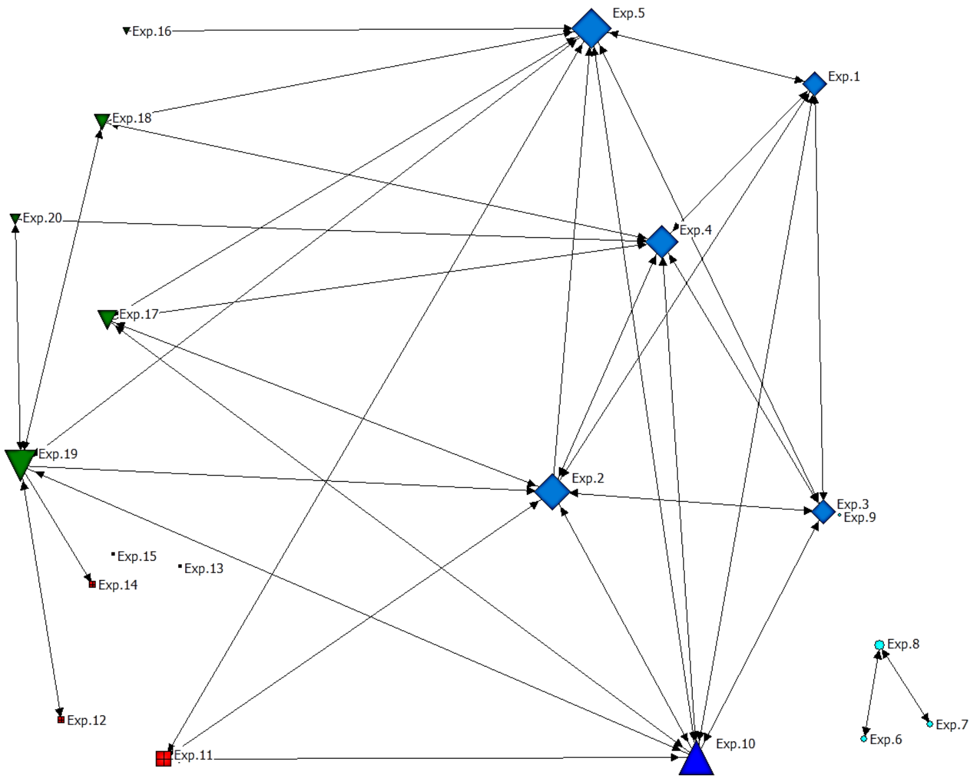


Figure 29: Centrality degree map of Brazilian LCA stakeholders' connection (Prepared with Ucinet®).

5.1.3 - Betweeness index of Brazilian LCA network

As explained in Chapter 4 of this thesis, the betweeness index refers to the degree to which an actor indirectly connects other actors through their direct links. The importance of this result in the system of data exchange and relations among LCA stakeholders in Brazil is expressed in Figure 30.

The graph shows that the largest intermediations in the network are carried out by the industry expert 19 and by the academia experts 5 and 4.

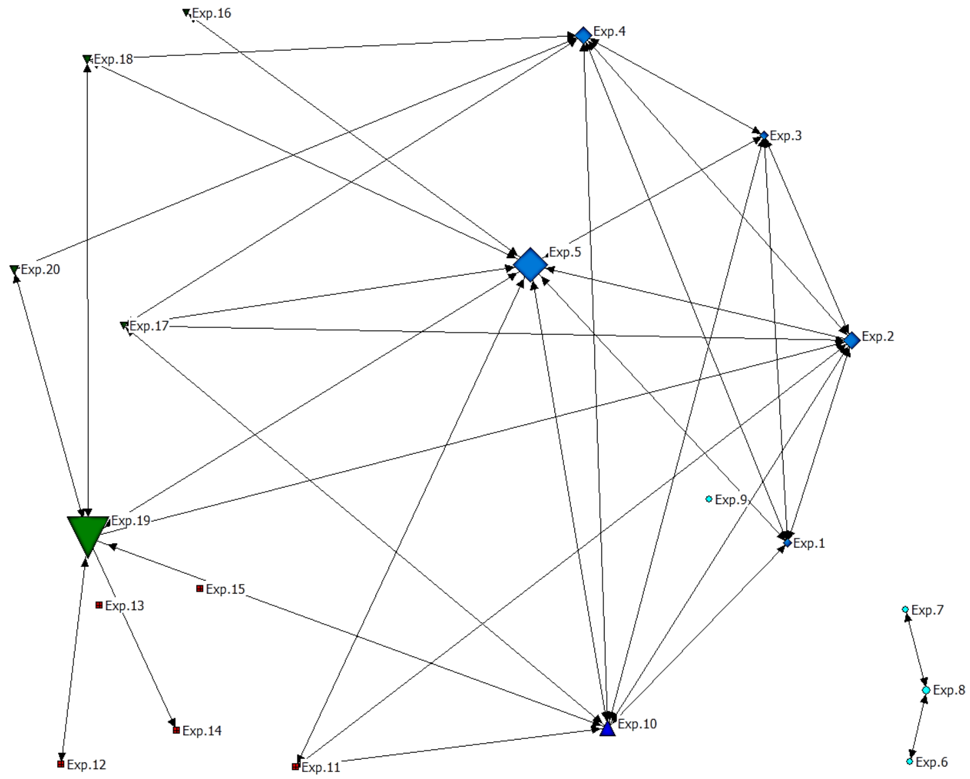


Figure 30: Betweenesses index map of Brazilian LCA stakeholder's connection (Prepared with Ucinet®).

5.1.4 - Closeness index of Brazilian LCA network

In this case, Figure 31 shows that industry expert actor 19 and expert actors from academy 5, 4, 2 and 10 have the ability to reach more players in this sample network.

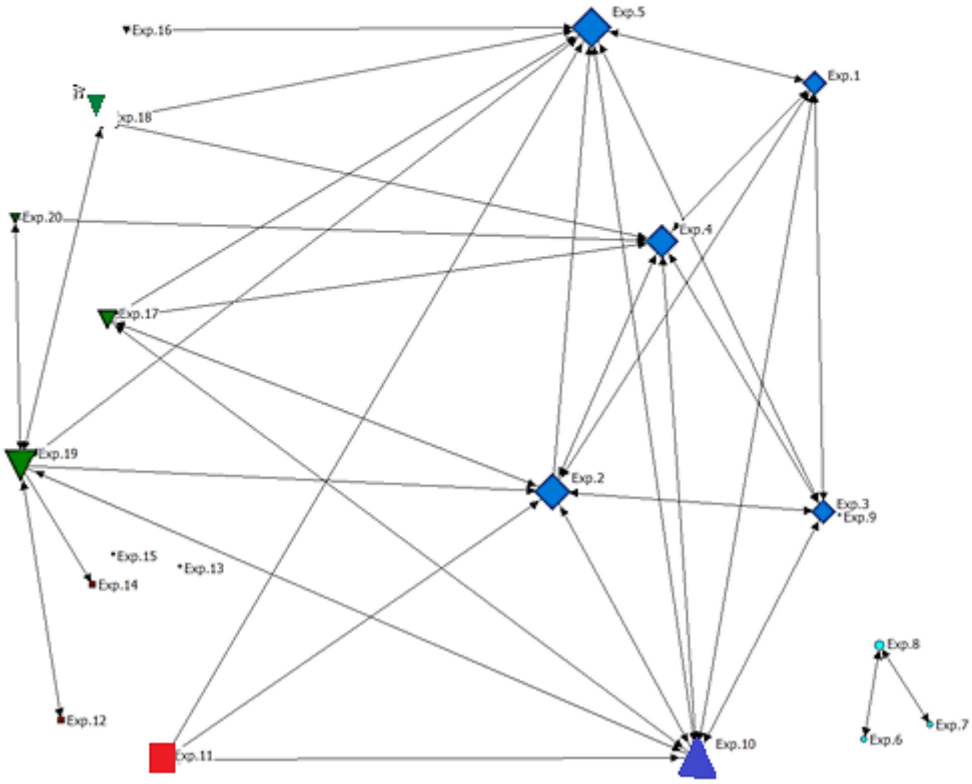
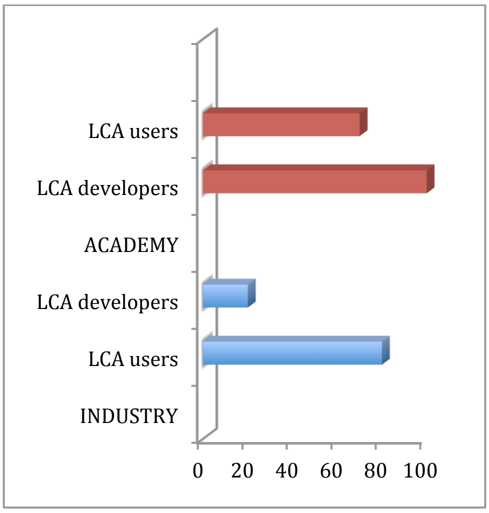


Figure 31: Closeness index map of Brazilian LCA stakeholder's connection.

5.2 - Interviews with LCA stakeholders in Spain

The first key points targeted the identification of LCA experts' role and their stakeholders' relationships. Figure 32 shows the experts role in the academy and industry fields. All experts were LCA users in both fields. However, all experts from academia are conducting research to improve the LCA method and only 20% of experts from industry do. All experts from industry have connections with industrial stakeholders and have some work connectivity with academics, and 60% of them have direct connections with governments, see Figure 33. In the academia, 70% of experts have direct connections with industrial stakeholders, and all of them interact with academicians, acting as researchers or professors.



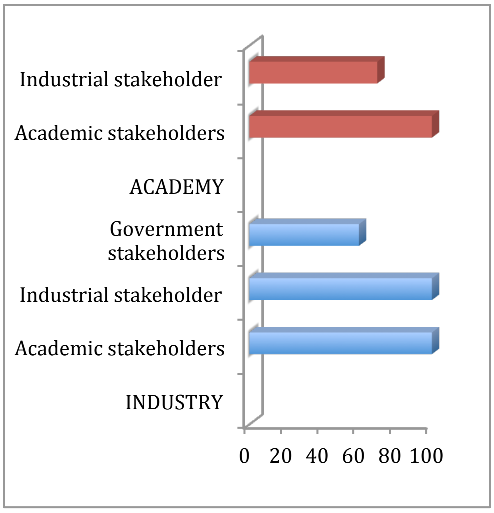


Figure 32: Classification of experts in focus group.

Figure 33: Identification of stakeholders' circles.

Regarding the diversity of information sources, Figure 34 shows how experts develop the environmental data collection to perform LCA studies. All experts from industry get primary data from their company, 90% of them compare their primary data with general data. 80% of industrial experts compare data from scientific literature and 60% of them get inputs from their sector. All experts from academia get data from both scientific and companies' databases and most of them use ecoinvent and LCA software databases. On other hand, 50% of this group gets data from other stakeholders which hold some information that may be useful for the study (Figure 34).

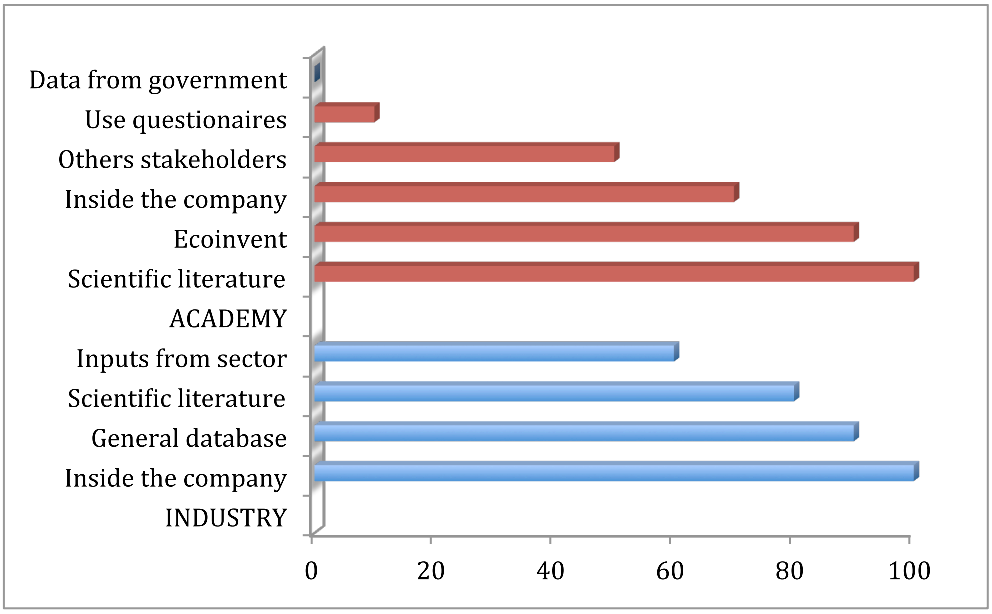


Figure 34: Identification of different data sources.

Figure 35 shows the main difficulties faced by experts regarding data gathering. All experts from academia said that most of the problems are related to variability and lack of standard data. For 90% of them, difficulties are related to finding all necessary data. 50% of experts complain because the communication between stakeholders is not efficient and about confidentiality of data sharing.

70% of experts from industry said that the biggest problem is to find the necessary data and the confidentiality of data sharing. In this line, 60% of experts complain because the data is not systematically measured and because of the lack of knowledge about LCA inside the industry. Finally, 50% of industrial experts complain because the communication with stakeholders is not efficient enough (Figure 35).

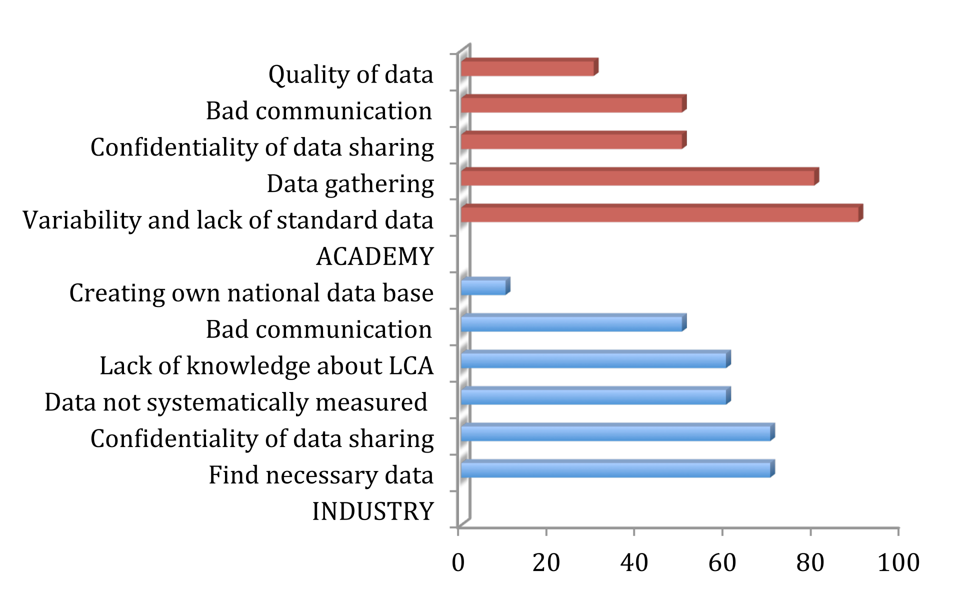


Figure 35: Main difficulties and barriers to get necessary data.

The results on data suitability are depicted in Figure 36. Results show that 70% of experts from academia compare primary data with other general databases before accepting it. On the other hand, 80% of experts from academia made sensitivity analysis of their data. With data coming from industries, 40% of experts from academia consider the industrial expertise of technical staff they interact with as a guarantee of the quality and reliability of data exchanged with them. However, 40% of experts from academia trust data coming from companies and sometimes consider necessary to make certain approximations and inferences to complete the LCI.

80% of experts from industry stated that they compare the data with other sources. 70% of those interviewed in industry consider the industrial expertise of the technical staff they interact with as a guarantee of the quality and reliability of the data exchanged with them. 50% of experts trust information shared by the company, without making data comparisons. 30% of experts prefer to measure data personally than rely on measurements made by others. Finally, 30 % of experts use sensitivity analysis.

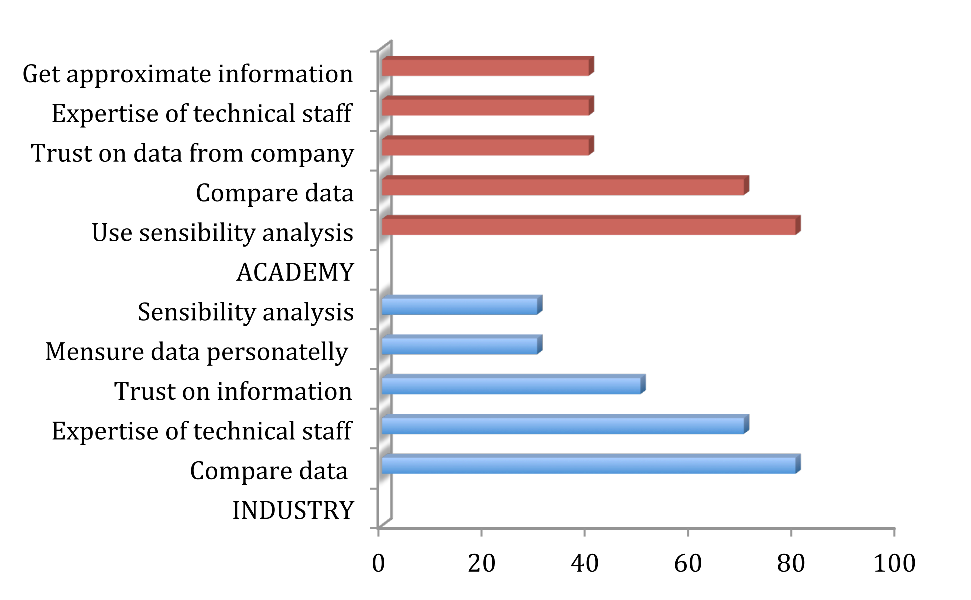


Figure 36: Identification when the data is suitable for the experts.

The results on data exchange are depicted in the Figure 37. Results show that 90% of industry experts share primary data only inside the company. Sharing information is essential to increase databases. In this regard, 70% of industrial experts try to share their results in scientific tools and publish them in governmental and industrial technical reports.

In the academia, 80% of experts try to publish the results of their LCA studies on scientific journals, but showing only general results without specific primary data. In this group, 40% of experts published and thus made public only some part of the results and consider confidenciality issues as a barrier to publish their work (Figure 37).

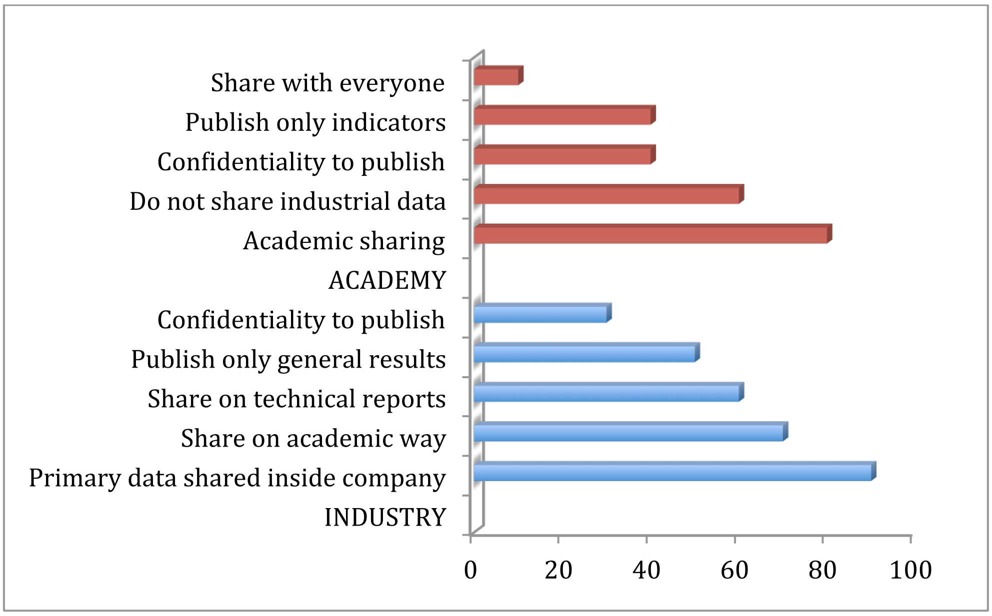


Figure 37: Classification of aspects of sharing information with stakeholders.

The results for the last two questions regarding the importance of sorting out information to sharing data and how aspects of sharing information are classified and handled by actors are depicted in Figure 38 and Figure 39. Figure 38 shows that 40% of the interviewed from academy do not publish complete LCA from industries because they worry about consumers misunderstanding results, even when positive results are given. Data confidentiality remains a strong barrier for 50% of experts from academia. Bad communication between stakeholders is a strong problem for 70% of the group from academia. Data collection difficulties is a problematic issue for 60% of the interviewed. In these interviews, for 40% of experts from academia, in some cases it is necessary to mask information in order to balance low quality results.

In the case of industrial experts, 80% of the interviewed do not publish their works because they worry about consumers misunderstanding results, even when positive results are given. Bad communication between stakeholders is a strong problem for 50% of them. 70% of industrial experts admit that companies worry about sharing their databases, while admitting confidentiality is a normal issue in the industry.

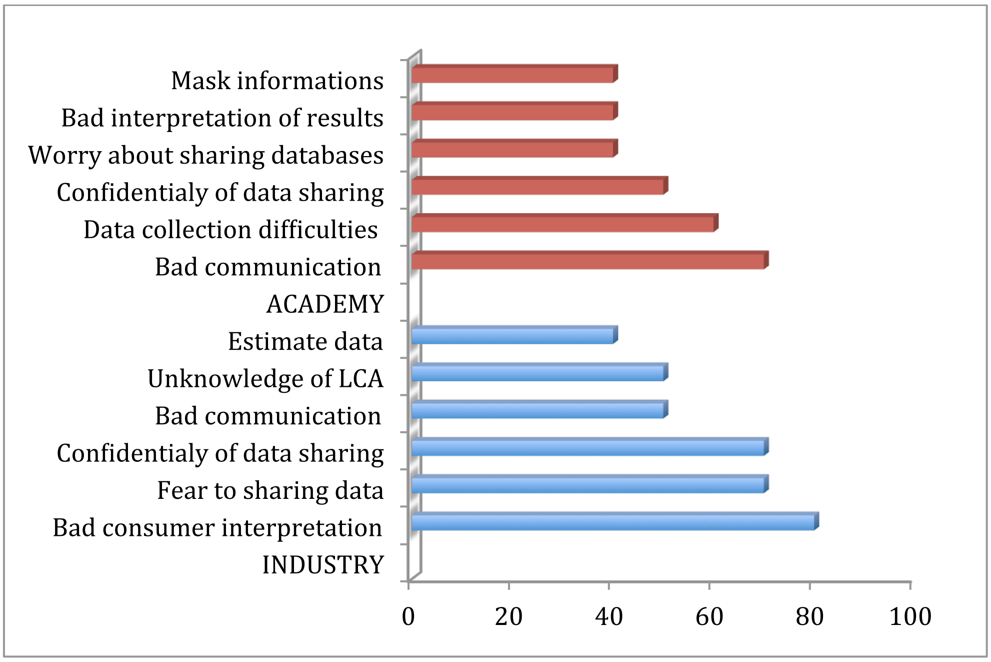


Figure 38: Main data sharing barriers in LCA studies.

All of the experts from academia reported that in most studies made for the industry, results are only shown in internal reports. Moreover, companies had the control of the publishing process, selecting which results can be included and where they should be published. Few experts of this focus group publish legal reports.

In the industry, 70% of experts signed a confidentiality agreement, which is a normal practice. For 60% of them all information remains inside the company. In essence, these answers show some problems related to data sharing from industry in both groups.

Finally, regarding confidentiality none of the experts from industry claimed to have difficulties using the internal environmental information of the companies, because most of them sign a confidentiality agreement which is considered a common practice for companies (see Figure 38). In the case of the academic group, 80% of experts claimed not having difficulty using the internal environmental information of the companies, because 50% of them signed a confidentiality agreement with the company, which is considered a common practice. Moreover, 40% of experts said that companies have the control of the publishing process, selecting which results can be included and where they should be published.

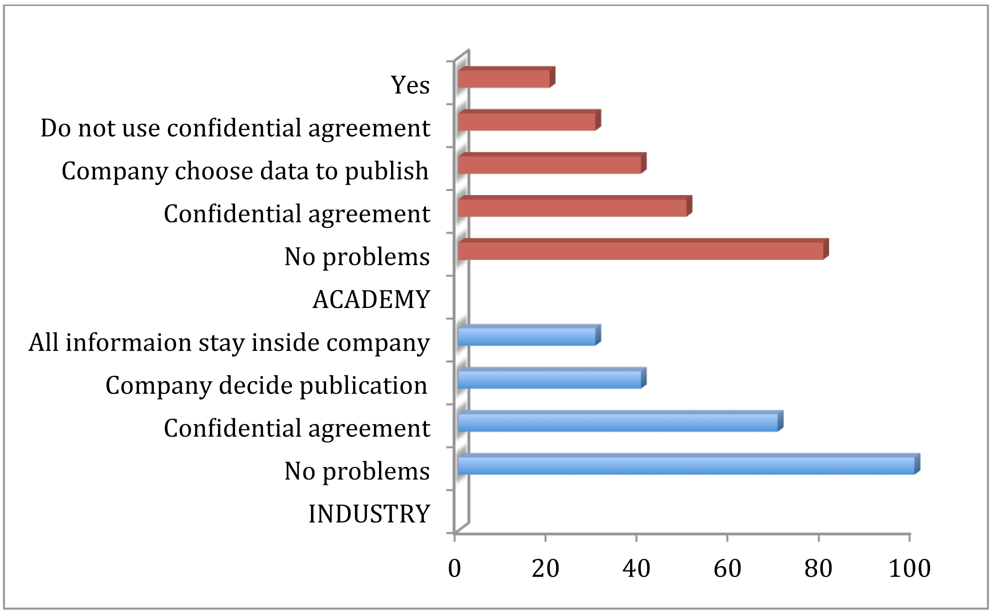


Figure 39:Confidential information in a LCA analysis.

5.2.1 - Surveys and social network analysis of Spanish LCA stakeholders

Figure 40 shows a graphical representation of the network of actors involved in the use or development of LCA tools in Spain. Arrows show the direction of the environmental information that can be unidirectional or bidirectional. Sections of the network analysis will be showed in later sections to better understand the relationships between actors.

This graphic presents a sociocentric network with a high degree of graphical density, decentralized, with high quantity of links or relations between the different nodes, and with NO presence of isolated nodes. Its conformation is not built on one or few central actors, but on multiple nodes that establish multiple relationships with each other. Some peripheral nodes can only communicate through some nodes (for example private companies or some research groups that perform LCA studies). It could be said that the fall of one of the nodes centralization would not necessarily lead to the disconnection of one or more nodes of the network as a whole, although their communication capacity would surely be affected.

The nodes are represented by colors, regrouping the academics on the right side and the companies on the left side to separate them by groups and facilitate their analysis.

The overall structure of the network and the level of integration allow identifying and separating the main components of database exchange in LCA in different parts of Spain.

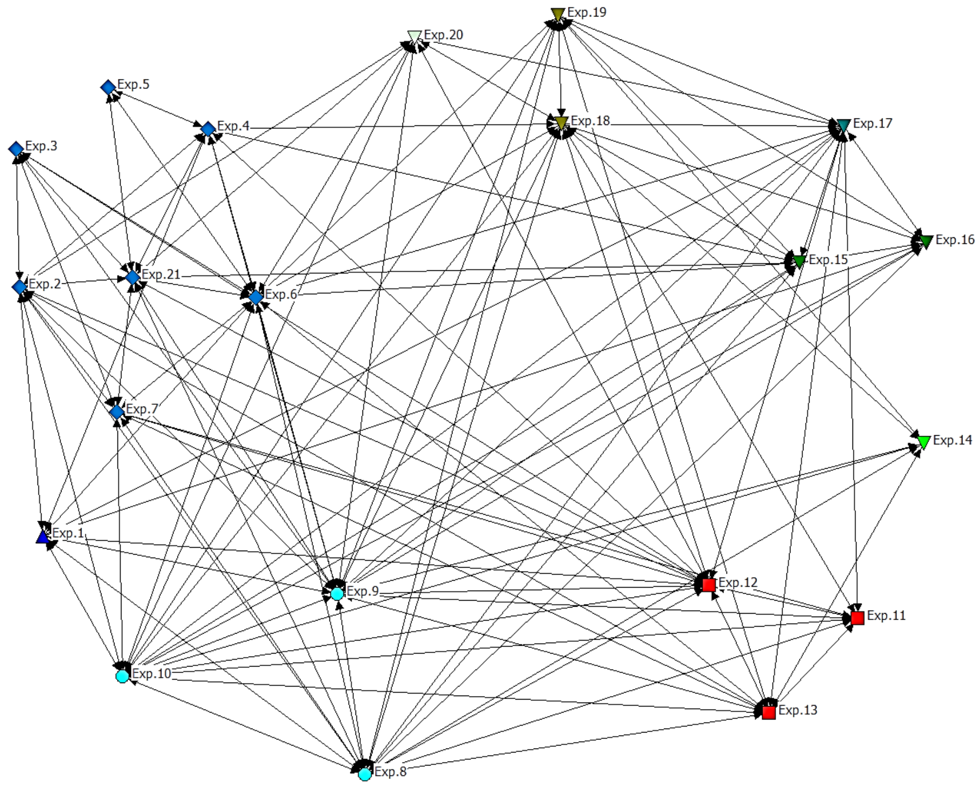


Figure 40: General map of Spanish LCA stakeholders' connection (Prepared with Ucinet®).

5.2.2 - Centrality degree of LCA stakeholders in Spain

Figure 41 shows the values of centrality degree, within the communication network of the LCA experts from Spain. As it can be seen, the nodes corresponding to UAB and Itene actors have higher indexes of centrality, that is, a greater degree of communication with other nodes within the network, accompanied by actors of other reference companies which work with LCA in Spain.

Regarding which actors are more informed (Indegree), the universities concentrate the largest sum of relations coming from other actors, see experts 9, 10 and 8 from UAB and expert 6 from UPV, followed by the companies Itene, Inèdit and Icta, represented by experts 12, 18 and 17 respectively.

Regarding which actors inform others more (Outdegree), the greater concentration is also referred to expert 9, coming from academy, and followed by expert 17 from Icta who represents the industry.

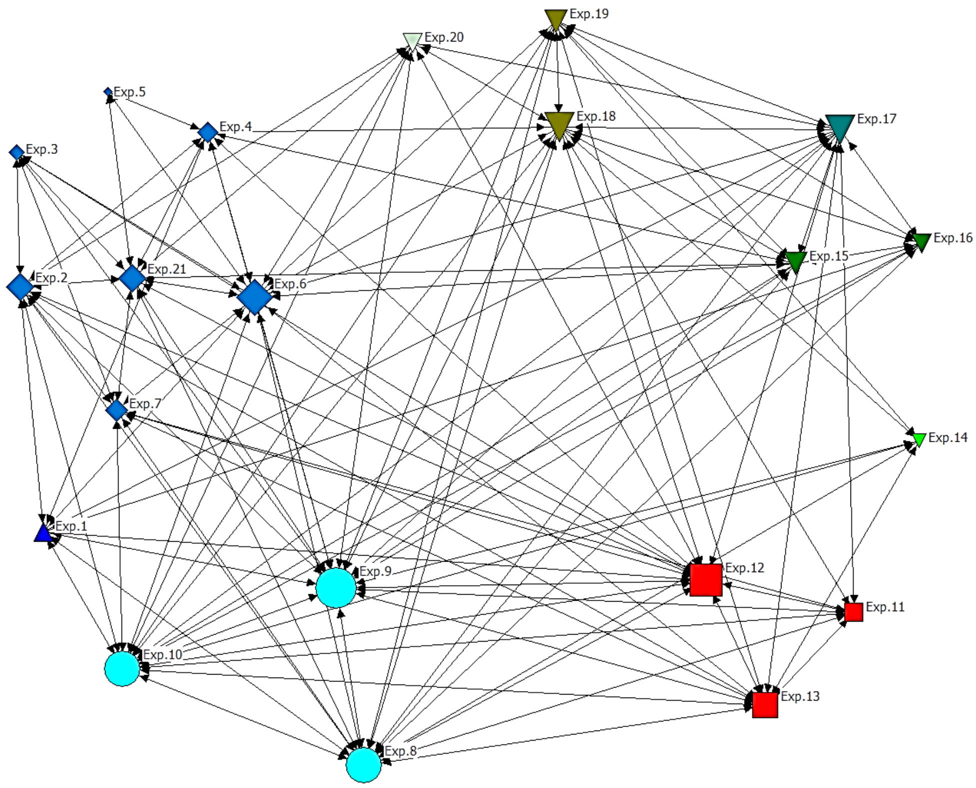


Figure 41: Centrality degree map of Spanish LCA stakeholders' connection.

5.2.3 - Betweeness index of Spanish LCA network

As explained in Chapter 4 of this thesis, the betweeness index refers to the degree to which an actor indirectly connects actors through their direct links, its importance in the system of data exchange and relations among LCA stakeholders in Spain is shown in Figure 42.

The graph shows that the largest intermediation in the network is carried out by the academy from experts 21, 6 and 9 and by the industry from expert 17 followed by expert 18.

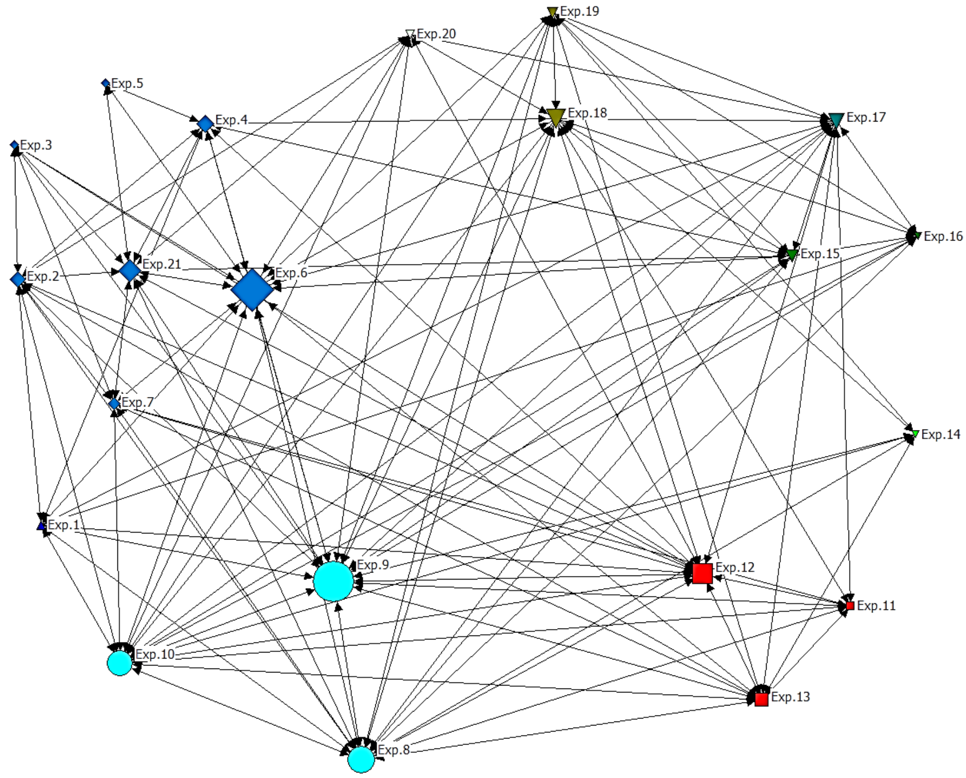


Figure 42: Betwenesses index map of Spanish LCA stakeholders' connection (Prepared with Ucinet®).

5.2.4 - Closeness index of Spanish LCA network

In this case, Figure 43 shows thatactors from industry, experts 12 and 17 and actors from academy, experts 8, 10, 6 and 9, have the ability to reach more players in this sample network.

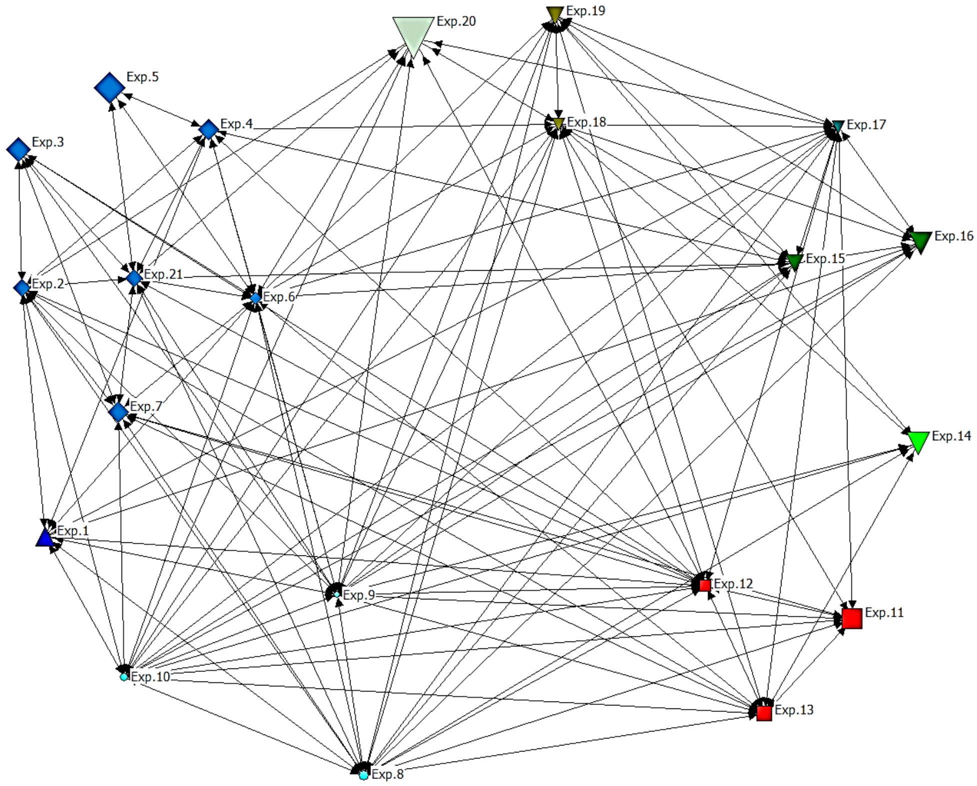


Figure 43: Closeness index map of Spanish LCA stakeholders' connection (Prepared with Ucinet®).

5.3 - Comparison of LCA stakeholder's networks in Brazil and Spain

Regarding data sources, the results are similar in both countries, as shown in Figures 23 and 35. It could be said that for academics the information comes from scientific literature, being Ecoinvent the most used general database. The situation is similar in the industrial sector. All experts from both countries get some data from companies and compare it with other general databases.

Regarding difficulties to get data needed to perform the Life Cycle Inventory, the lack of national databases is a bigger problem for academics from Brazil than from Spain, (see Figures 24 and 36). For industry experts in both countries, the biggest problem is that companies do not systematically measure data. Half of the experts from the Spanish academia also recognized bad communication as a problem to be solved.

When it comes to identifying expert criteria to evaluate the collected data quality, most experts from academy and industry in both countries compare their data with other databases and scientific publications before using them, (see Figures 24 and 37). An important difference between Brazilian and Spanish experts from academia is that Brazilian experts have more trust in the information directly coming from companies than Spanish experts. In Spain, academics use more frequently the sensitivity analysis in their LCAs than in Brazil. Another difference in the industrial sector is that Brazilian experts are more willing to accept the quality of data when it seems coherent for them than their Spainish counterparts. In the case of the Spanish group, technical experience in the sector is very important when it comes to consider the quality of collected data.

When it comes to share data and results, (see Figures 25 and 38), academics share results in scientific ways in both countries. However, in Spain more primary data is used to publish than in Brazil, where most academics only share general results. It is worth stating that in Brazil many LCA studies are sponsored by the government.

Regarding barriers and problems for data sharing (see Figures 26 and 39), in the Brazilian academia all interviewed experts claim that the industry has fear to share its data, but the industry itself does not consider having fear to do it. In Spain, academics do not consider that the industry has fear to share data, but most of industrial LCA experts think it does. Confidentiality is more problematic for Brazilian academics than for Spanish ones. Conversely, confidenciality issues are more problematic for the Spanish industry experts than for the Brazilians ones. It is worth stating that experts from industry in Spain worry about consumers misunderstanding results, even when positive results are given.

Regarding the way confidential information is handled (see Figures 27 and 40), in both countries most experts affirm they have no major difficulties to publish LCAs results, but in Brazil is more common to sign confidentiality agreements than in Spain.

Regarding academia and industry relationships, it could be said that LCA academia experts have more connections with industry in Spain than in Brazil.

Finally, when comparing the social network analysis between Brazil and Spain in terms of centrality, betweeness and closeness indexes the results are as follows:
Centrality: The indegree and the outdegree are concentrated in Universities in both countries, but in Spain there are more universities than in Brazil and they also have more industrial actors involved. The outdegree is balanced between both groups.

Betweenness: In Brazil the largest intermediation is carried out by one member, both in academia and industry. In Spain, the largest intermediation is carried out by academia, but some companies have strong indirect actors' connections.
Closeness: Actors from academy and industry in Spain have the ability to reach stakeholders in the same network. In Brazil only actors from academia do.

5.4 - Results of critical review literature on the Agri-food sector (Phase 2)

At this point of the thesis, results are presented from phase two of this research regarding assessment of information quality and quantity in the Agri-food industry.

Twenty variables considered equally important when performing a study of life cycle assessment were identified. A brief description of selected variables and the way they are measured is shown in Table 17.

Table 17: Characterization of variables.

N	VARIABLES	Discrimination	Characterization	Nominal	Ordinal	Scale
1	Field	LCA from agriculture or food manufacturing	Categorical	Agro/ Food/ Agri-food	-	-
2	Location	Country of study	Categorical	Country name	-	-
3	Packaging material	Is packaging considered on the LCA study of the product?	Categorical/ Quantitative	Yes/No	High/ medium/ low	kg
4	Source of data	Where data come from (primary data measured and/or data from general database)?	Categorical	Database name	-	-
5	Primary data vs General data	Data coming from only primary data versus data coming from general data base and mixing of both	Categorical	Primary/ General/ Primary and General	-	-
6	Impact characterization method	Classes representing environmental issues of concern	Categorical	Name	-	-

N	VARIABLES	Discrimination	Characterization	Nominal	Ordinal	Scale
7	Category indicators	Quantifiable resources/emissions/substances representing each impact category	Categorical	Name	-	-
8	Final point category	Method used to do the study	Categorical	Name		-
9	ISO 14040 settings	Use of ISO as a guidance	Categorical	Yes/No (if yes→With/ Without extra points		-
10	Type	Consideration of system expansion to calculate the impacts (Attributional or Consequential)	Categorical	a-LCA/c-LCA	-	-
11	Functional unit	What functions are used to numerically represent the impact assessed	Categorical	-	-	-
12	Allocation	Key Factor (Economic, mass, energetic…) to be focused when partitioning the input/output flows in the system under study	Categorical	Yes/No	Economic/ mass/ energy	-
13	Credits recycling	Are Recycled materials included or not to reduce the impact on process?	Categorical	Yes/No	High/ medium/ low	Kg/L
14	Detailed level of LCA	How complete is the LCA? (simplified or complete)	Categorical	Simplified/ Complete	-	-
15	System boundaries	Is partly based on a subjective choice to determine the scope of study	Categorical	Cradle to: gate, consumers or grave	-	-
16	Food losses consideration	Consideration of food losses on the study to calculate the impact of end of life	Categorical	Yes/No	High/ medium/ low	kg

N	VARIABLES	Discrimination	Characterization	Nominal	Ordinal	Scale
17	Includes uncertainty assessment	Uncertainty assessment included or not on the LCA study	Categorical	Yes/No	-	-
18	Transportation impacts	Consideration or not of transport impact in the study	Categorical	Yes/No	High/ medium/ low	km
19	Shannon Index	Entropy calculation	Categorical/ Quantitative	-	-	-
20	Equitability	Equitability of impact categories used in sample of LCA studies of this thesis	Categorical/ Quantitative	-	-	-

Critical review

The 70 full articles analyzed according to the checklist containing the set of selected variables are shown in Table 18.

Table 18: List of 70 scientific publications analyzed (source, title, authors, and year of publication).

LCA 1	Journal of Environmental Science and Technology	Closing Data Gaps for LCA of Food Products: Estimating the Energy Demand of Food Processing	Neus Sanjuań, FranziskaStoessel, and StefanieHellweg	2013
LCA 2	International Journal of Life Cycle Assessment (IJLCA)	Land use impacts on biodiversity in LCA: proposal of characterization factors based on functional diversity	Souza D. et al	2013
LCA 3	Journal Cleaner Production	Life cycle assessment application in the fruit sector: State of the art and recommendations for environmental declarations of fruit products	Cerutti A. et al	2014
LCA 4	Journal Cleaner Production	Life cycle assessment of Italian high quality milk production. A comparison with an EPD study	Fantin V. et al	2012
LCA 5	International Journal of Life Cycle Assessment	Life cycle assessment of vegetable products: a review focusing on cropping systems diversity and the estimation of field emissions	Perrin A. et al	2014
LCA 6	International Journal of Life Cycle Assessment	Regionalization of agri-food Life Cycle Assessment: A review of studies in Portugal and recommendations for the future	Morais T. et al	2016

LCA 7	Journal of food engineering	A review of life cycle assessment (LCA) on some food products	Roy P. et al.	2008
LCA 8	Journal of Environmental Management	The life cycle of rice: LCA of alternative agri-food chain management systems in Vercelli (Italy)	Gian Andrea Blengini and Mirko Busto	2009
LCA 9	Resources, Conservation and Recycling	The utility of Life Cycle Assessment in the ready meal food industry	Luis Alberto Calderón, Loreto Iglesias, Adriana Laca, Mónica Herrero, Mario Díaz	2010
LCA 10	Journal Cleaner Production	Life Cycle Assessment of multiyear peach production	Vinyes E. et al	2015
LCA 11	Packaging Technology and Science	A Comparative Life Cycle Assessment of Disposable and Reusable Packaging for the Distribution of Italian Fruit and Vegetables	Levi M. et al	2013
LCA 12	Science of the Total Environment	Accounting for land use in life cycle assessment: The value of NPP as a proxy indicator to assess land use impacts on ecosystems	Taelman S. et al	2016
LCA 13	Journal Cleaner Production	Modelling of food loss within Life Cycle Assessment: from current practice towards a systematization	Corrado S. et al	2016
LCA 14	International Journal of Life Cycle Assessment	Impact Categories for Life Cycle Assessment Research of Seafood Production Systems: Review and Prospectus	Pelletier N. et al	2007
LCA 15	International Journal of Life Cycle Assessment	The need for co-product allocation in the life cycle assessment of agricultural systems—is Biophysical allocation progress?	Mackenzie S. et al	2016
LCA 16	Revista Española de Estudios Agrosociales y Pesqueros	Assurance on sustainability reports in the agri-food industry	Araya H. et al	2015
LCA 17	journal of Cleaner Production	Life cycle assessment in Brazilian agriculture facing worldwide trends	Ruviaro C. et al	2012
	Journal Cleaner Production	In quest of reducing the environmental impacts of food production and consumption	Sala S. et al	2016
LCA 18	Journal Cleaner Production	Pollinators in life cycle assessment: towards a framework for impact assessment	Crenna E. et al	2016
LCA 19	International Journal of Life Cycle Assessment	Higher accuracy in N modeling makes a difference	Meier M. et al	2014
LCA 20	International Journal of Life Cycle Assessment	Environmental assessment of Peruvian anchoveta food products: is less refined better	Avadí A., Pierre Fréon & Isabel Quispe	2014
LCA 21	LCA Food 2014	Assessing the land use impacts of agricultural practices on ecosystems	Assumpció Antón et al.	2014

LCA 22	LCA Food 2014	The applicability of LCA to evaluate the key environmental challenges in food supply chains	Aronsson A. et al.	2014
LCA 23	LCA Food 2014	Environmental impacts of imported versus locally-grown fruits for the French market as part of the AGRIBALYSE® program	Basset-Mens C. et al.	2014
LCA 24	LCA Food 2014	Integrating social and economic criteria in the carbon footprint analysis in sheep dairy farms	Inmaculada Batalla, et al.	2014
LCA 25	LCA Food 2014	An innovative methodology combining Life Cycle Assessment of a product with the assessment of its Quality; case of the French vineyards	Sandra Beauchet, et al.	2014
LCA 26	LCA Food 2014	Assessing the materiality of various sustainability issues in the agrifood sector with L C A-based tools: 3 case studies	Catherine Benoit Norris, et al.	2014
LCA 27	LCA Food 2014	From wheat to beet challenges and potential solutions of modeling crop rotation systems in LCA	Gerhard Brankatschk, Matthias Finkbeiner	2014
LCA 28	LCA Food 2014	Agricultural valorization of organic residues: Operational tool for determining the nitrogen mineral fertilizer equivalent	Doris Brockmann, Ophélie Négri, Arnaud Hélias	2014
LCA 29	LCA Food 2014	Challenges of comparing food and feed products from different countries of origin	Maria Bystricky, Thomas Nemecek, Martina Alig, Gérard Gaillard	2014
LCA 30	LCA Food 2014	Spatial and Temporal Scale of Eco-label for Agricultural products - case study of milk production	Wenhao Chen, Nicholas M. Holden	2014
LCA 31	LCA Food 2014	AGRIBALYSE®, the French LCI Database for agricultural products: high quality data for producers and environmental labelling	Colomb et al.	2014
LCA 32	LCA Food 2014	Impact of transportation on the environmental performance of Brazilian banana production	Leda Coltro, Thiago Urtado Karaski	2014
LCA 33	LCA Food 2014	Consequential and attributional modeling in life cycle assessment of food production systems	Randi Dalgaard, Ivan Muñoz	2014
LCA 34	LCA Food 2014	Methodologies accounting for indirect Land Use Change (iLUC): assessment and future development	Michele De Rosa et al.	2014
LCA 35	LCA Food 2014	Key Environmental Performance Indicators for a simplified LCA in food supply chains	Geneviève Doublet et al	2014
LCA 36	LCA Food 2014	Agri-Footprint; a Life Cycle Inventory database covering food and feed production and processing	Bart Durlinger et al.	2014

LCA 37	LCA Food 2014	Environmental impacts of German food consumption and food losses	Ulrike Eberle, Jacob Fels	2014
LCA 38	LCA Food 2014	Progress Report: Methodology of Chilean Food & Agriculture LCI Database	Cristian Emhart et al.	2014
LCA 39	LCA Food 2014	Integrating Nutritional Benefits and Impacts in a Life Cycle Assessment	Alexi Ernstoff et al.	2014
LCA 40	LCA Food 2014	Incorporating Health Impacts from Exposure to Chemicals in Food Packaging in LCA	Alexi Ernstoff et al.	2014
LCA 41	LCA Food 2014	Environmental impacts of extensive outdoor pig production systems in Corsica.	Sandrine Espagnol, Julie Demartini	2014
LCA 42	LCA Food 2014	Considering human exposure to pesticides in food products: Importance of dissipation dynamics	Peter Fantke, Ronnie Juraske, Olivier Jolliet	2014
LCA 43	LCA Food 2014	Life cycle assessment of Brazilian cashew.	Maria Cléa Brito de Figueirêdo et al.	2014
LCA 44	LCA Food 2014	Contemporary comparative LCA of commercial farming and urban agriculture for selected fresh vegetables consumed in Denver, Colorado.	Stephen Fisher, Arunprakash Karunanithi	2014
LCA 45	LCA Food 2014	Life Cycle Assessment towards a Sustainable Food Supply: A review of BASF strategy	Markus Frank et al.	2014
LCA 46	LCA Food 2014	Co-products from meat processing: the allocation issue	Armelle Gac et al.	2014
LCA 47	LCA Food 2014	Comparing two LCA approaches for the transport of milk from farms to processing plants in Switzerland	Camille B.H. Girod, Silvia M.R.R. Marton	2014
LCA 48	LCA Food 2014	Assessing GHG mitigation options for crops at regional level using ecosystem modelling and LCA	Pietro Goglio et al.	2014
LCA 49	LCA Food 2014	LCA study of unconsumed food and the influence of consumer behavior	Lisa Marie Gruber et al.	2014
LCA 50	LCA Food 2014	Critical review of allocation rules: the case of Finnish rainbow trout	Hanna Hartikainen, Frans Silvenius, Juha-Matti Katajajuuri	2014
LCA 51	LCA Food 2014	Introduction of uncertainty into trade-offs between productivity and life cycle environmental impacts in rice production systems: Assessing the effectiveness of nitrogen-concentrated organic fertilizers	Kiyotada Hayashi et al.	2014
LCA 52	LCA Food 2014	Use of fertilizing residues by agricultural activities in LCA studies	Arnaud Hélias, Doris Brockmann	2014
LCA 53	LCA Food 2014	Analysis of the determinants of the economic and environmental performance of Swiss dairy farms in the alpine area	Pierrick Jan et al.	2014

LCA 54	LCA Food 2014	Analysis of inconsistencies between Product Category Rules in the same supply chain: a case study of food PCRs	Kristian Jelse et al.	2014
LCA 55	LCA Food 2014	ONE TWO WE: Life cycle management in canteens together with suppliers, customers and guests	Niels Jungbluth et al.	2014
LCA 56	LCA Food 2014	Life Cycle Assessment of Cheese Manufacturing in the United States	Daesoo Kim et al.	2014
LCA 57	LCA Food 2014	Climate impact of producing more grain legumes in Europe	Marie Trydeman Knudsen et al.	2014
LCA 58	LCA Food 2014	Implementing LCA Results for Primary Production in the Agri-Food Sector	Kerrianne Koehler-Munro et al.	2014
LCA 59	LCA Food 2014	Creating coherent life cycle databases for ecodesign and product declaration of agroindustrial products: how to deal with contradictory methodological requirements	Jens Lansche et al.	2014
LCA 60	LCA Food 2014	Comparing UK turkey production systems using analytical error propagation in uncertainty analysis	Ilkka Leinonen et al.	2014
LCA 61	LCA Food 2014	LCA of vegetarian burger packed in bio-based polybutylene succinate	Leo Breedveld et al	2014
LCA 62	LCA Food 2014	Challenges of comparing food and feed products from different countries of origin	Maria Bystricky et al.	2014
LCA 63	LCA Food 2014	Environmental impacts of genetic improvement in growth rate and feed conversion in fish farming under density and nitrogen limitation	M. Besson et al	2014
LCA 64	LCA Food 2014	LCA of perennial crops: implications of modeling choices through two contrasted case studies	C. Bessou et al	2014
LCA 65	LCA Food 2014	Application of Dempster-Shafer theory to integrate methods to propagate variability and epistemic uncertainty in agricultural LCA	Xiaobo Chen, Michael Corson	2014
LCA 66	LCA Food 2014	Environmental impacts of milk production in southern Belgium: estimation for nine commercial farms and investigation of mitigation via better manure application	Michaël Mathot et al	2014
LCA 67	LCA Food 2014	Building consensus for assessing land use impacts on biodiversity in LCA	Llorenç Milà i Canals et al	2014
LCA 68	LCA Food 2014	Implications of increasing demand for freshwater use from the water footprint of irrigated potato production in Alberta	Aung Moe et al	2014

LCA 69	LCA Food 2014	Influence of site conditions and production system on the environmental impacts of domestic and imported cheese	Martina Alig et al.	2014
LCA 70	LCA Food 2014	LCA study of unconsumed food and the influence of consumer behavior	Lisa Marie Gruber, Christian Peter Brandstetter, Ulrike Bos and Jan Paul Lindner	2014

5.4.1 - Descriptive analysis of variables

<u>1 - Field </u>(Agro/Food/Agri-food):

Several studies have shown the behavior of companies regarding sustainability assurance from a multisector perspective, but very few studies have focused on a particular industry. Thus, the aim of this thesis is to perform an exploratory analysis about sustainability assurance in the Agri-food sector/industry. This sector is divided in three ramifications in order to achieve a better understanding of this research: the Agro industry; the Food industry and the Agri-food industry, this last category combining LCA studies from agriculture and manufacturing (Figure 44).

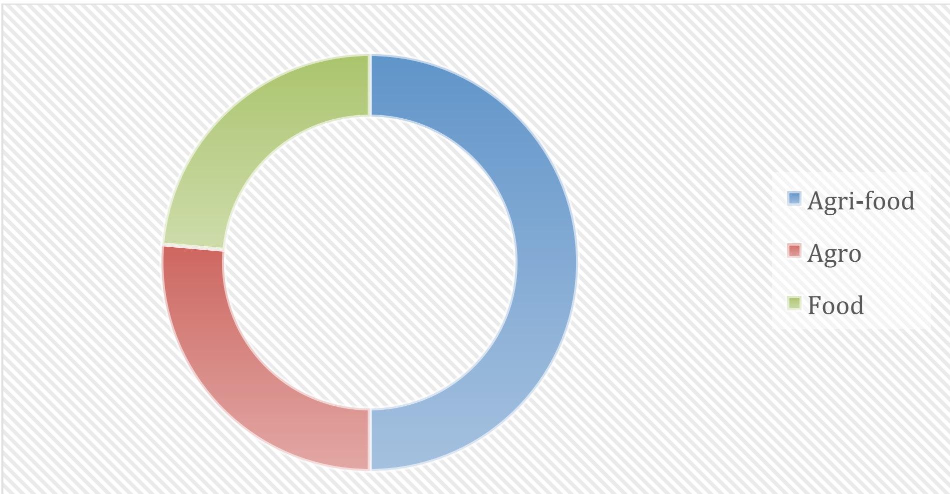


Figure 44: Field distribution among LCA studies.

<u>2 - Location:</u>

In this extensive critical analysis of scientific publications of LCA studies around the world, almost 75% of them are studies performed in Europe. Three countries account for almost 50% of the sample of LCA studies analyzed: France (12 cases), Spain (10) and Italy (10), as shown in Figure 45.

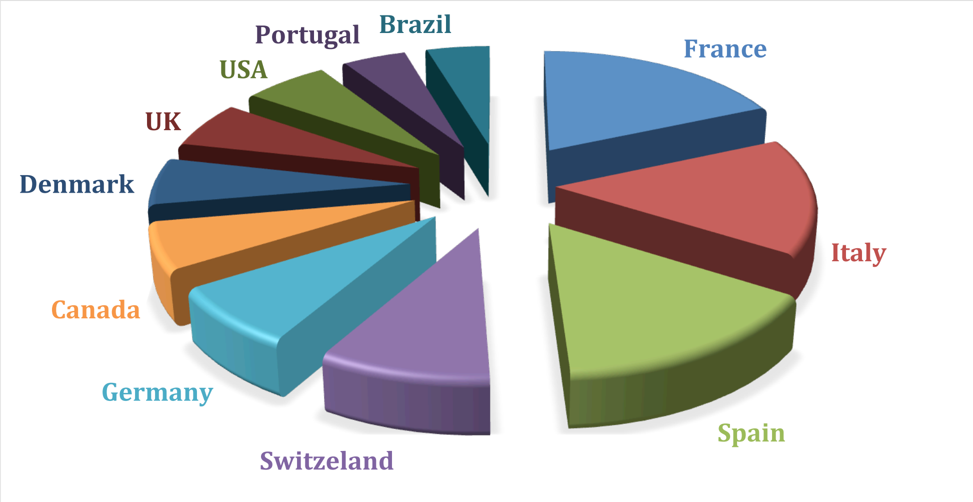


Figure 45: Distribution by country of the selected LCA studies.

3 - Packaging Material:

Figure 46 shows that 40 out of 70 studies do not consider packaging within the impact categories. Among the 30 studies which consider packaging impact, 15 rank it as low, because it has no significant impact in comparison with other impact categories, 6 rank it as medium, and only 9 as high.

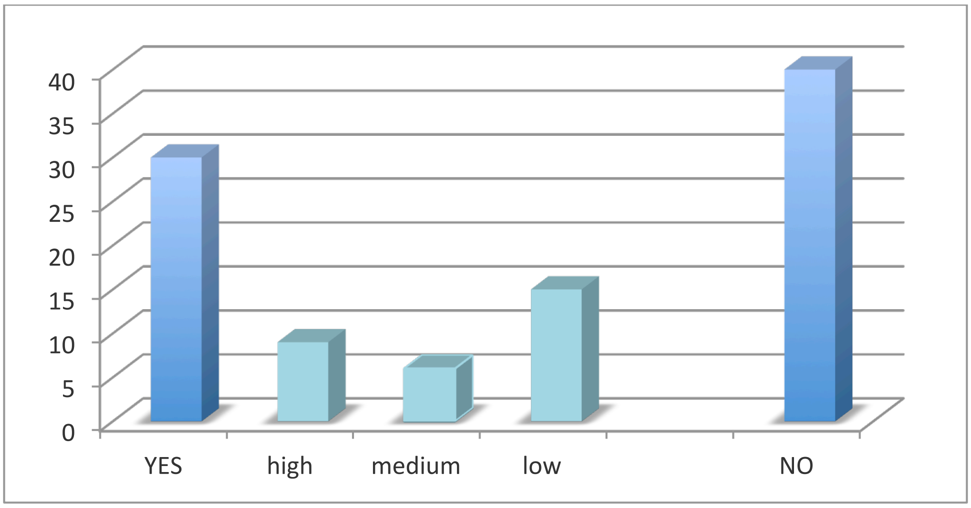


Figure 46: Impact packaging consideration.

4 – Source of Data:

The source of data is very important when performing an LCA study. The quantity and, even more important, the quality of data is crucial for obtaining good results. In this research, it is possible to observe that most of the studies use data from general databases, from primary sources and from other scientific publications (see Figure 47). In the case of the Agri-food sector, there are production databases in many countries and, in numerous cases, these databases are compared to other commercial databases. The most used database is Ecoinvent, 28 out of 70 studies used it. Some 18 works used only primary data from the company, 16 used only data from scientific publications, and 58 works used data from other commercial databases.

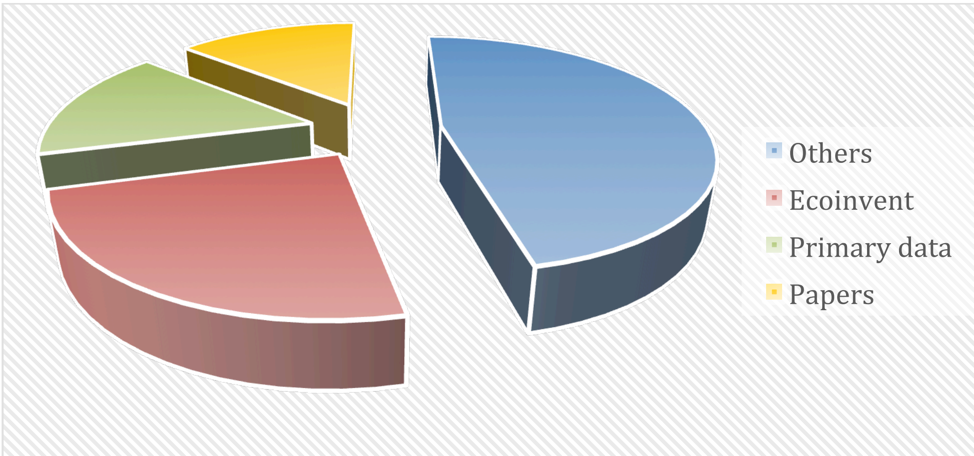


Figure 47: Source of data.

5- Primary Data/General Data (G.P&GP):

The selected LCA studies from the Agri-food sector showed that for the most part data came only from general databases, 38 out of 70 studies, 19 works mixed primary and general databases, and only 13 of them exclusively used primary data from the company, see Figure 48.

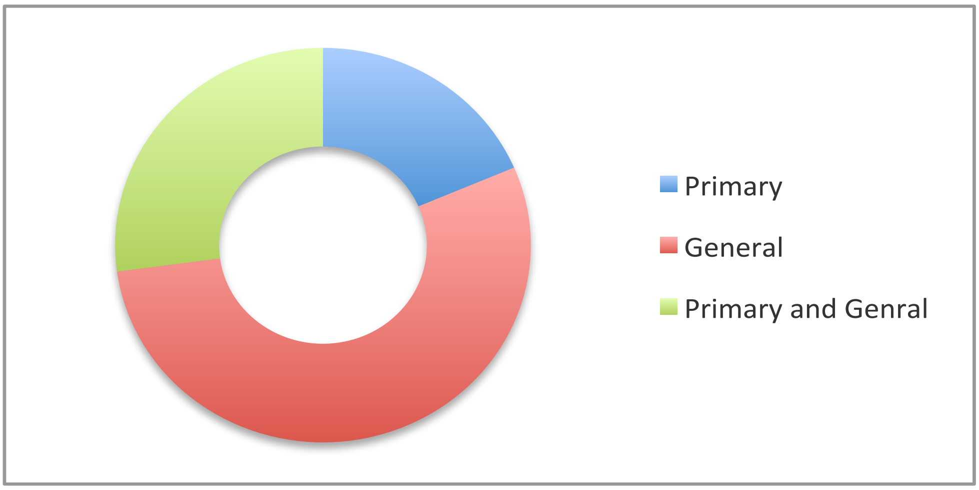


Figure 48: Primary data, general databases and primary and general databases.

6 - Impact Characterization Method:

In this scientific review, 19 different methods used in LCA studies were found, as shown in Figure 49 where only the unique point methods were shown in detail. ReCiPe represents the more used method with 23 cases, ILCD 2011 is the second with 17 cases and CML-IA was used in 12 cases.

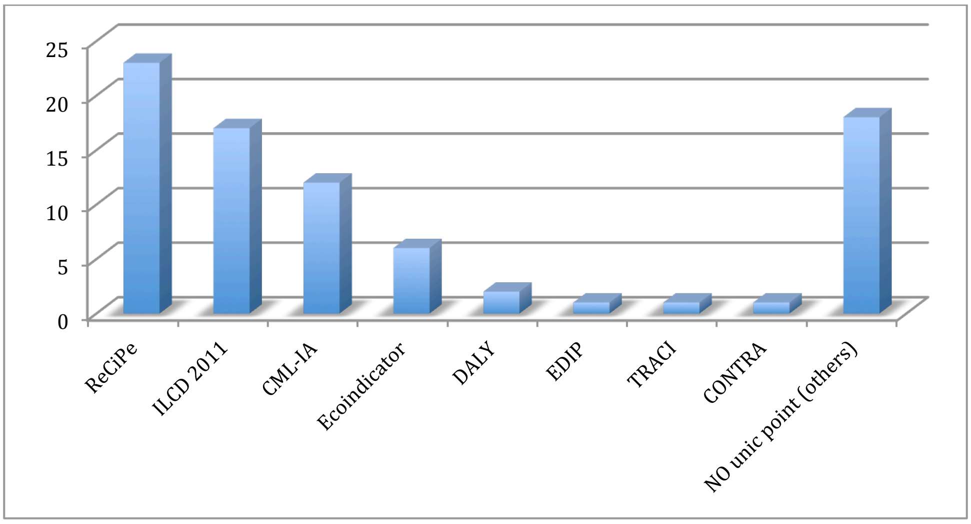


Figure 49: More commonly used methods to define environmental issues.

No unique point methods are described in Table 19 to show other methods commonly used.

Table 19: Impact Characterization Method found on literature.

No unic point methods
IPCC
Agrammon
PAS2050
USLCI
World impact+
USES-LCA
CERES-EGC
UseTox
Alpha
Cumulative energy demand
WRMM

7 - Category Indicator:

47 different impact categories can be found in the literature, but in the case of LCA studies from the Agri-food industry and from the analyzed sample, 35 were identified. From this diversity of impact categories, it is clear that only a few of them are often used. In this thesis, Climate Change (CC) (54 cases), Land Use (34 cases), Acidification (31 cases) and Eutrophication potential (24 cases) are the most commonly used impact categories. Those impact categories used in less than 10 cases where codified as "other", see Figure 50.

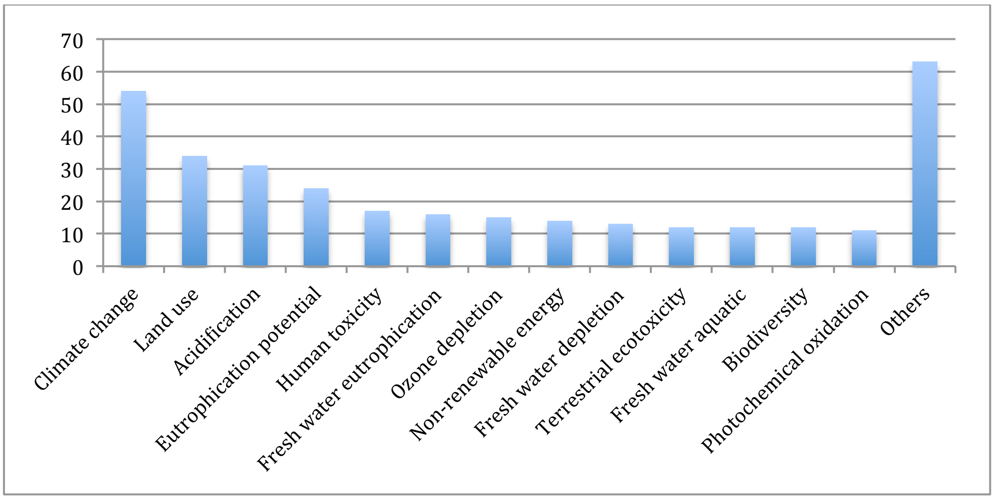


Figure 50: Commonly used impact categories in Agri-food LCAs.

8 - Final Point Category:

This category was chosen to know how many inputs were used to evaluate each impact category in each LCA study. The study shows that there is a great variation in both the number of impact categories considered and the number of inputs evaluated in each impact category. The average of input compounds considered was around four, as Figure 51 shows.

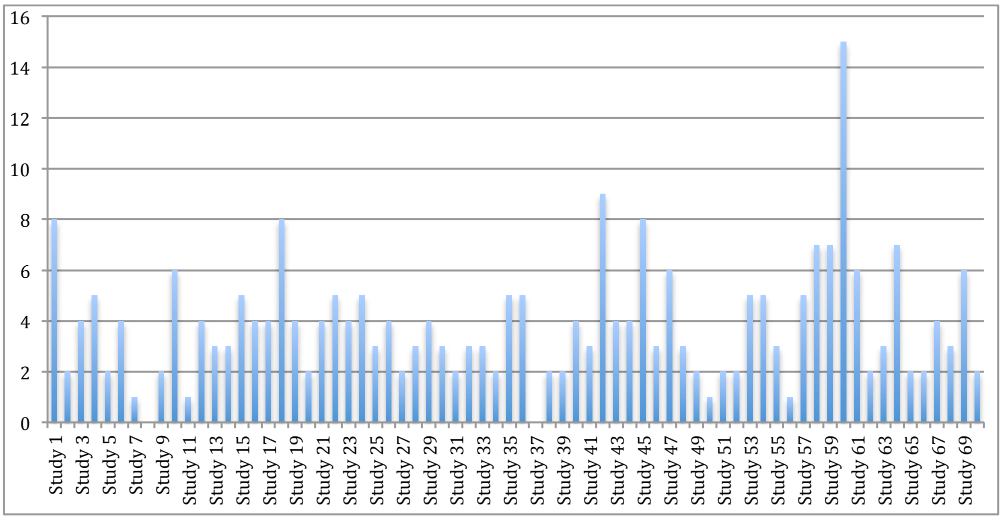


Figure 51: Final point category.

9 – ISO 14040 Settings:

Basic steps taken according to the ISO 14040 standard and extra points performed (see Table 17) were analyzed in the selected LCA studies. The checklist result is shown in Table 20.

Table 20: Phases classification of ISO 14040.

ISO 14040: Definitions			
Points	Points of ISO definitions	Number of definition follower	
1	Definitions/scope	70 followers	Minimum ISO standard
2	Life Cycle Inventory (LCI)	70 followers	
3	Life Cycle Inventory Analysis (LCIA)	70 followers	
4	Interpretation	70 followers	
5	Reporting/Critical Review	53 followers	Extra points
6	Limitation of LCA	54 followers	
7	Relationship with phases	33 followers	

All articles used the four standard points described in Table 21 (Definitions/scope, Life Cycle Inventory (LCI), Life Cycle Inventory Analysis (LCIA) and Interpretation), but extra points suggested by the mentioned ISO standard have not been considered in many cases. "NO relationship with the other LCA phases" is the extra point least performed by researchers, as shown in Figure 52.

Table 21: Classification of ISO phases (basic and extra points) used to identify scientific studies review.

Studies	Basic ISO steps standard				Extra points ISO		
	Definitions/ Scope	LCI	LCIA	Interpretation	Critical review	Limitations	Relationship phases
1	X	X	X	X	x	x	x
2	X		X	X	x	x	-
3	X			X	x	-	-
4	X	X	X	X	x	-	-
5	X			X	x	-	-
6	X		X	X	-	-	-
7	X	X	X	X	x	-	-
8	X	X	X	X	x	x	-
9	X	X	X	X	-	-	-
10	X	X	X	X	x	x	X
11	X	X	X	X	x	x	X
12	X	X	X	X	-	-	-
13	X	X	X	X	-	x	-
14	X	X	X	X	x	x	X
15	X	X	X	X	x	x	-
16	X	X	X	X	x	x	X
17	X	X	X	X	x	-	-
18	X	X	X	X	x	x	X
19	X	X	X	X	-	X	-
20	X	X	X	X	x	x	X
21	X	X	X	X	x	x	X
22	X	X	X	X	x	x	X
23	X	X	X	X	-	X	-
24	X	X	X	X	x	x	X
25	X	X	X	X	-	x	-
26	X	X	X	X	-	x	X
27	X	X	X	X	x	x	-
28	X	X	X	X	x	x	X
29	X	X	X	X	x	x	-
30	X	X	X	X	-	x	-
31	X	X	X	X	-	-	-
32	X	X	X	X	x	x	X
33	X	X	X	X	x	-	-
34	X	X	X	X	x	x	X

Studies	Basic ISO steps standard				Extra points ISO		
	Definitions/ Scope	LCI	LCIA	Interpretation	Critical review	Limitations	Relationship phases
35	X	X	X	X	-	-	-
36	X	X	X	X	x	x	x
37	X	X	X	X	-	-	-
38	X	X	X	X	x	x	X
39	X	X	X	X	-	-	-
40	X	X	X	X	x	x	X
41	X	X	X	X	x	x	-
42	X	X	X	X	x	x	-
43	X	X	X	X	x	x	-
44	X	X	X	X	x	x	X
45	X	X	X	X	-	x	x
46	X	X	X	X	-	x	-
47	X	X	X	X	x	x	-
48	X	X	X	X	x	x	X
49	X	X	X	X	-	x	-
50	X	X	X	X	x	-	-
51	X	X	X	X	x	x	-
52	X	X	X	X	x	x	X
53	X	X	X	X	x	x	x
54	X	X	X	X	x	x	X
55	X	X	X	X	x	x	X
56	X	X	X	X	x	x	X
57	X	X	X	X	x	x	-
58	X	X	X	X	x	x	X
59	X	X	X	X	x	x	-
60	X	X	X	X	x	x	X
61	X	X	X	X	x	x	X
62	X	X	X	X	x	x	-
63	X	X	X	X	-	-	-
64	X	X	X	X	x	x	X
65	X	X	X	X	x	x	-
66	X	X	X	X	x	-	-
67	X	X	X	X	x	-	-
68	X	X	X	X	x	-	X
69	x	x	x	x	x	x	-
70	x	x	x	x	x	x	x

(X) ISO phase Considered; (-) ISO phase not considered

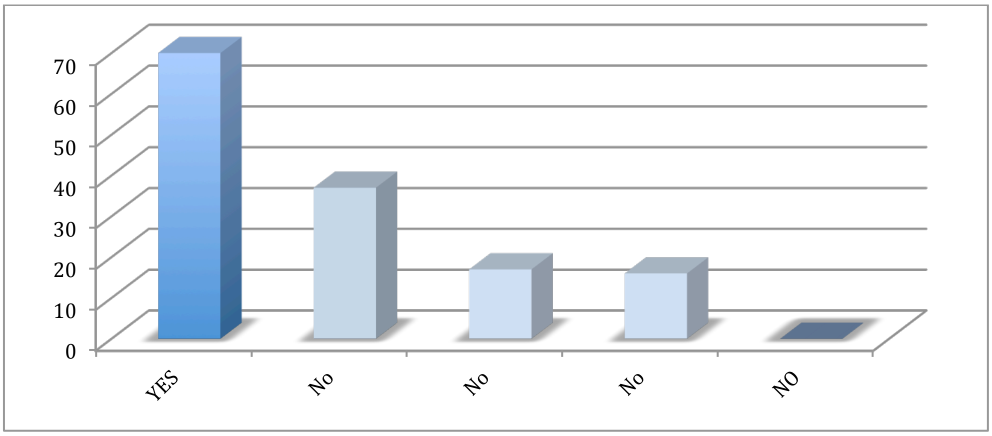


Figure 52: ISO basic followers (Yes) and complement ISO 14040 points applied to LCA.

10 - Type:

In LCA studies, a decision can be made to perform the study using two different system expansions: attributional, that uses a "restricted" vision of the boundaries to be analyzed, and consequential, that uses a broader expansion of the system to be analyzed. In this case, it is clear that most of the studies used the attributional approach (53). Only 17 studies out of 70 used the consequential approach, as shown in Figure 53.

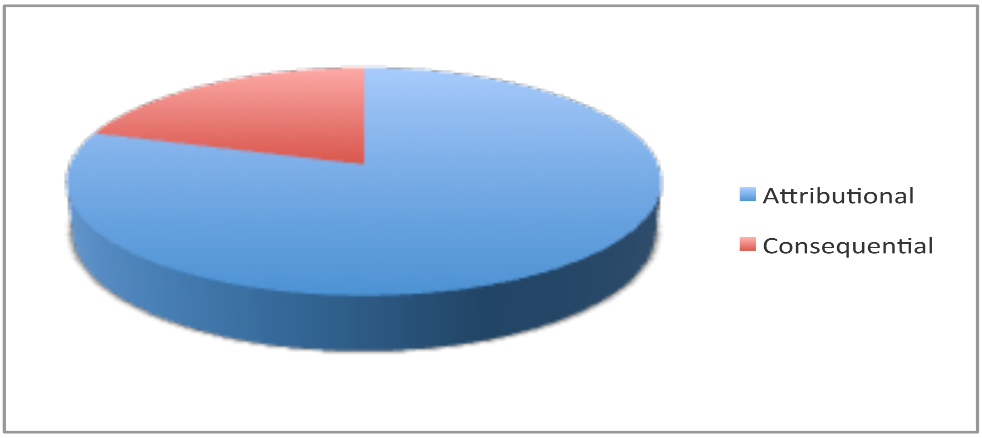


Figure 53: System expansion to calculate the impacts (Attributional or Consequential).

11 - Functional Unit:

Most of the studies used Kg as the functional unit, as can be seen in Figure 54.

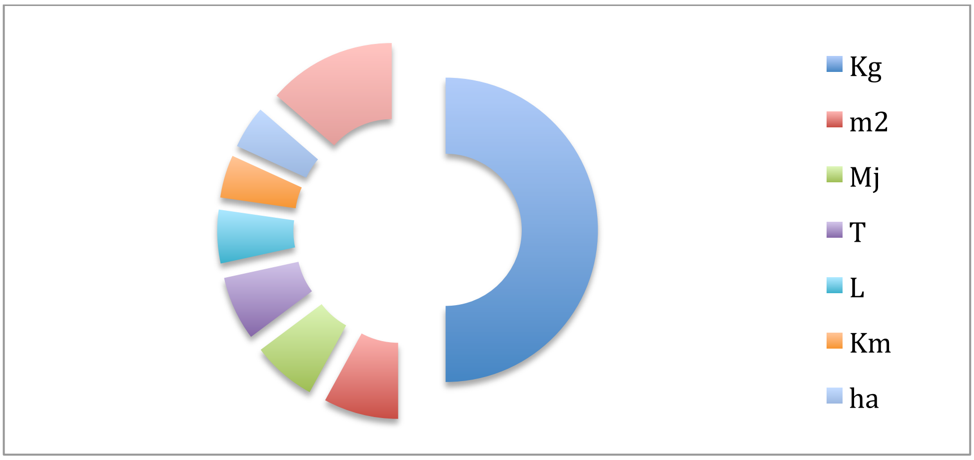


Figure 54: Function units used in Agri-food LCA´s.

12 - Allocation:

54 studies considered co-product as allocation in their systems. The second allocation more commonly used was the economic allocation, with 34 studies, followed by mass allocation with 22 studies, as seen in Figure 55.

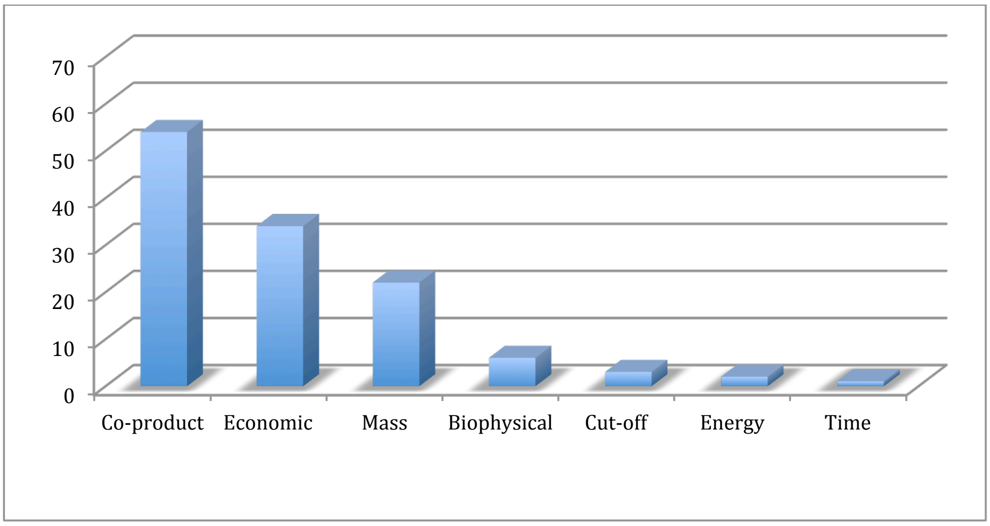


Figure 55: Criteria of allocation consideration in each study.

13 - Credits Recycling:

45 studies did not include the recycling phase in the LCA impact calculation. Only 25 studies considered the packaging recycling impact of products at different levels (see Figure 56).

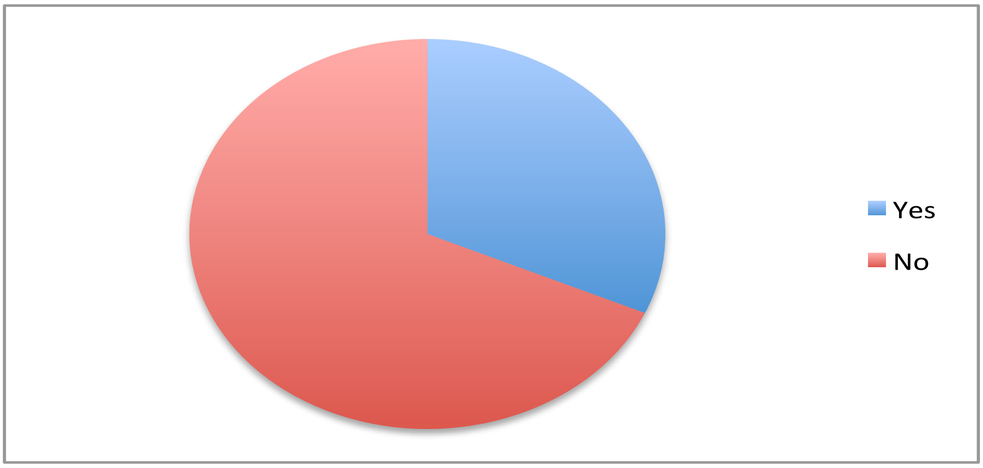


Figure 56: Inclusion of recycled materials in the impact calculation.

<u>14 - Detail level of LCA:</u>

Some 17 out of 70 studies used a simplified LCA study (see figure 57).

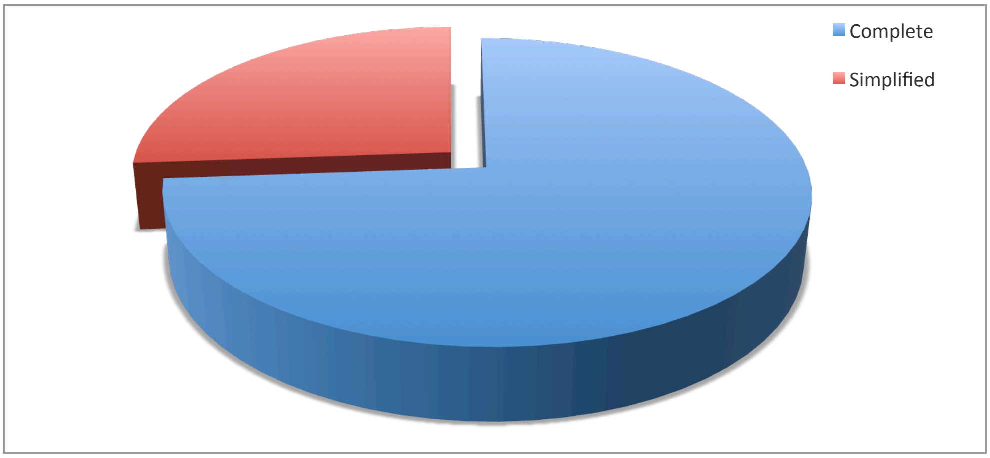


Figure 57: Level of detail of the study (Complete or detailed).

<u>15 - System Boundaries:</u>

System boundaries are an important aspect of LCAs. In this research, 70 selected studies were classified according to four different system boundaries. Regarding this aspect, results showed that 31 studies used cradle to gate as system boundaries, 15 studies used farm to gate, 10 studies used farm to consumer and only nine used the complete system: cradle to grave, as shown in Figure 58.

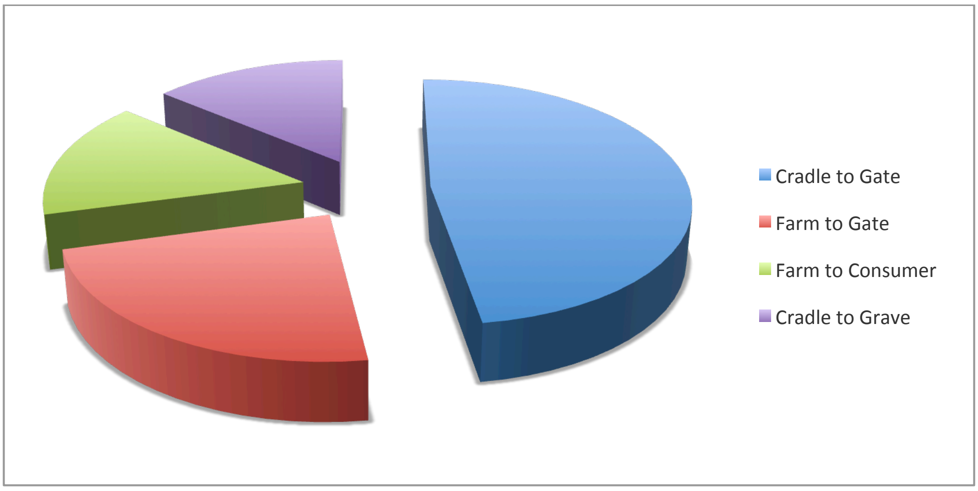


Figure 58: System boundaries.

16 - Food Losses Consideration:

Most of the LCA studies do not consider food losses (see Figure 59).

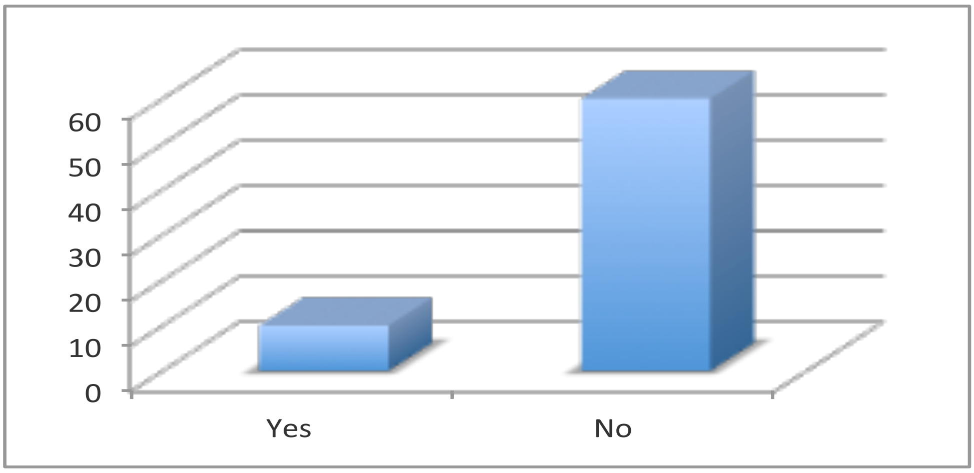


Figure 59: Number of studies that consider food losses.

17 - Uncertainty Assessment Inclusion:

Only 29 out of 70 studies used sensitivity analysis. Thus, 58% of the studies in this research did not use any sensitivity analysis (see Figure 60).

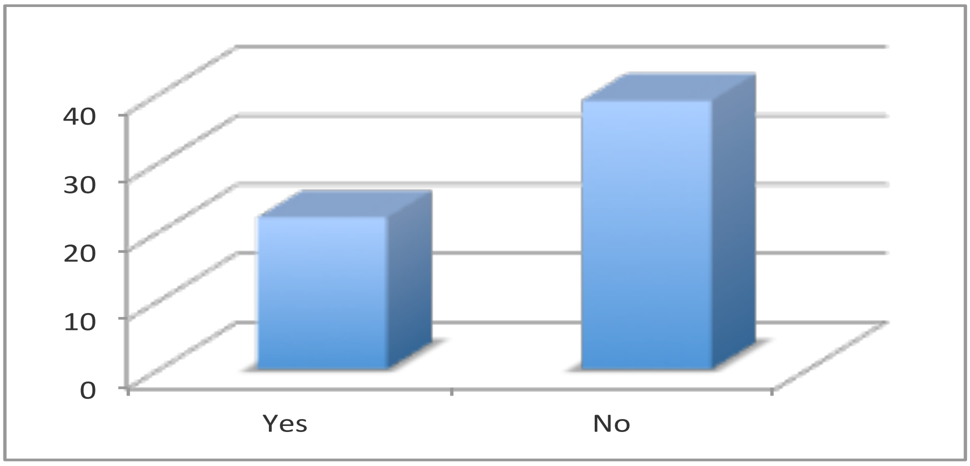


Figure 60: Using uncertainty factor or sensitivity analysis.

18 – Inclusion of Transportation Impacts:

In this research, 54 studies considered transportation as an impact category. Among them, 16 cases ranked transportation impacts as high, 13 cases ranked them as medium, and 25 cases ranked them as low (see Figure 61).

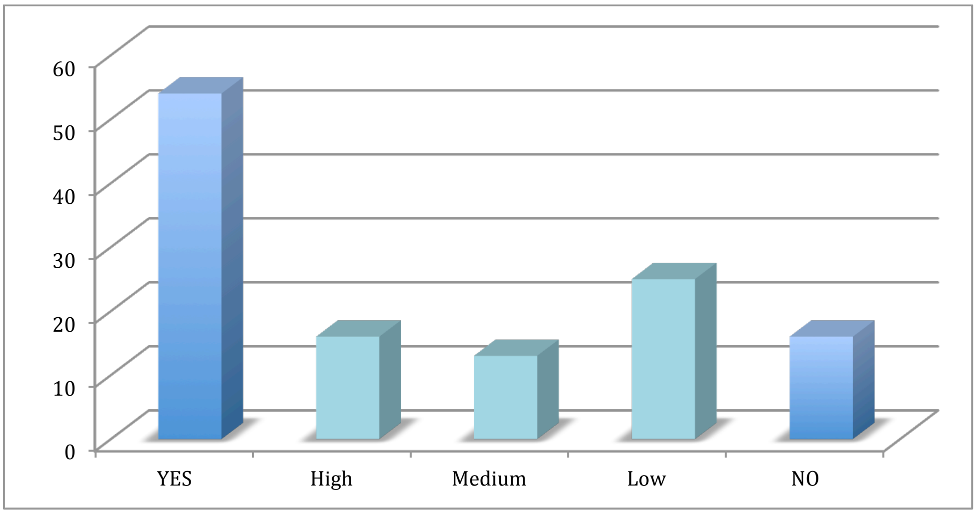


Figure 61: Consideration of transportation impacts in the study.

19 - Shannon Index:

Table 22 shows the results of the Shannon index values for the LCA studies analyzed in this thesis.

Table 22: Shannon index result for each LCA study.

LCA´s	H	LCA´s	H	LCA´s	H	LCA´s	H
LCA 1	0,895	LCA 21	3,647	LCA 41	0,497	LCA 61	1,271
LCA 2	0,512	LCA 22	0,866	LCA 42	1,662	LCA 62	0,502
LCA 3	0,993	LCA 23	3,647	LCA 43	0,550	LCA 63	0,788
LCA 4	1,033	LCA 24	0,866	LCA 44	0,775	LCA 64	1,291
LCA 5	0,314	LCA 25	0,459	LCA 45	1,591	LCA 65	0,409
LCA 6	0,916	LCA 26	0,730	LCA 46	0,497	LCA 66	0,409
LCA 7	0,287	LCA 27	0,314	LCA 47	0,945	LCA 67	0,419
LCA 8	0,000	LCA 28	3,989	LCA 48	0,497	LCA 68	0,409
LCA 9	0,314	LCA 29	0,855	LCA 49	0,448	LCA 69	0,541
LCA 10	1,037	LCA 30	0,497	LCA 50	0,091	LCA 70	0,091
LCA 11	0,091	LCA 31	0,236	LCA 51	0,406		
LCA 12	0,730	LCA 32	0,497	LCA 52	0,502		
LCA 13	3,910	LCA 33	0,497	LCA 53	1,113		
LCA 14	0,497	LCA 34	0,487	LCA 54	1,113		
LCA 15	0,866	LCA 35	1,041	LCA 55	0,788		
LCA 16	1,000	LCA 36	1,041	LCA 56	0,091		
LCA 17	0,997	LCA 37	0,000	LCA 57	1,113		
LCA 18	3,024	LCA 38	0,381	LCA 58	1,674		
LCA 19	3,568	LCA 39	0,181	LCA 59	1,400		
LCA 20	0,693	LCA 40	3,766	LCA 60	1,719		

Table H = Shannon índex representation.

A summary of Shannon descriptive Statistics is shown in Table 23.

Table 23: General Shannon index of 70 LCAs.

Descriptives

			Statistic	Std. Error
Shannon	Mean		,8262	,05441
	95% Confidence Interval for Mean	Lower Bound	,7177	
		Upper Bound	,9348	
	5% Trimmed Mean		,8239	
	Median		,9420	
	Variance		,207	
	Std. Deviation		,45527	
	Minimum		0,00	
	Maximum		1,89	
	Range		1,89	
	Interquartile Range		,72	
	Skewness		-,165	,287
	Kurtosis		-,524	,566

Figure 62 represents the box and whiskers graphic of the Shannon index for the total sample.

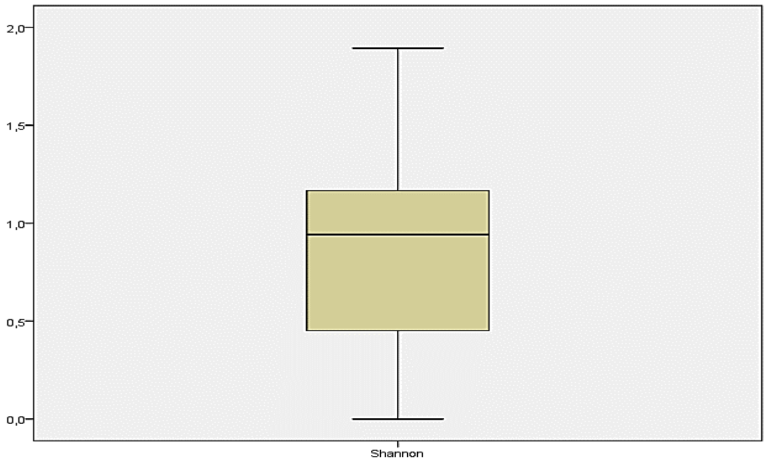


Figure 62: Box graphic average of Shannon index for all analyzed LCAs.

Table 24: Threshold definition for Shannon index qualification**.**

		Percentiles						
		5	10	**25**	50	75	90	95
Weighted Average(Definition	Shannon	0,0000	,0199	,4510	,9420	1,1660	1,3605	1,5649
	Equitability	0,0000	,0693	,6930	1,2425	1,6090	1,9460	2,0790
Tukey's Hinges	Shannon			,4510	,9420	1,1660		
	Equitability			,6930	1,2425	1,6090		

<u>**20 – Equitability**</u>

Table 25 shows the result of Equitability for each LCA analyzed in this thesis.

Table 25: Equitability result of each LCA study.

LCA´s	Equitability	LCA´s	Equitability	LCA´s	Equitability	LCA´s	Equitability
LCA 1	0,430	LCA 21	2,631	LCA 41	0,452	LCA 61	0,709
LCA 2	0,738	LCA 22	0,538	LCA 42	0,756	LCA 62	0,724
LCA 3	0,716	LCA 23	2,631	LCA 43	0,397	LCA 63	0,717
LCA 4	0,642	LCA 24	0,538	LCA 44	0,559	LCA 64	0,720
LCA 5	0,454	LCA 25	0,418	LCA 45	0,765	LCA 65	0,590
LCA 6	0,661	LCA 26	0,526	LCA 46	0,452	LCA 66	0,590
LCA 7	0,000	LCA 27	0,454	LCA 47	0,587	LCA 67	0,381
LCA 8	0,000	LCA 28	3,631	LCA 48	0,452	LCA 68	0,372
LCA 9	0,454	LCA 29	0,617	LCA 49	0,646	LCA 69	0,391
LCA 10	0,579	LCA 30	0,452	LCA 50	0,000	LCA 70	0,000

LCA´s	Equitability	LCA´s	Equitability	LCA´s	Equitability	LCA´s	Equitability
LCA 11	0,000	LCA 31	0,340	LCA 51	0,586		
LCA 12	0,526	LCA 32	0,452	LCA 52	0,724		
LCA 13	3,559	LCA 33	0,452	LCA 53	0,691		
LCA 14	0,452	LCA 34	0,702	LCA 54	0,691		
LCA 15	0,538	LCA 35	0,647	LCA 55	0,717		
LCA 16	0,621	LCA 36	0,647	LCA 56	0,000		
LCA 17	0,719	LCA 37	0,000	LCA 57	0,691		
LCA 18	1,454	LCA 38	0,346	LCA 58	0,805		
LCA 19	2,574	LCA 39	0,261	LCA 59	0,719		
LCA 20	0,702	LCA 40	2,717	LCA 60	0,747		

A summary of equitability descriptive Statistics is shown in Table 26.

Table 26: General equitability for 70 LCAs.

Descriptives

			Statistic	Std. Error
Equitability	Mean		1,1884	,06915
	95% Confidence Interval for Mean	Lower Bound	1,0505	
		Upper Bound	1,3264	
	5% Trimmed Mean		1,2012	
	Median		1,2425	
	Variance		,335	
	Std. Deviation		,57858	
	Minimum		0,00	
	Maximum		2,20	
	Range		2,20	
	Interquartile Range		,92	
	Skewness		-,463	,287
	Kurtosis		-,207	,566

Figure 63 shows the box and whiskers graphic of the equitability index for the total LCA sample.

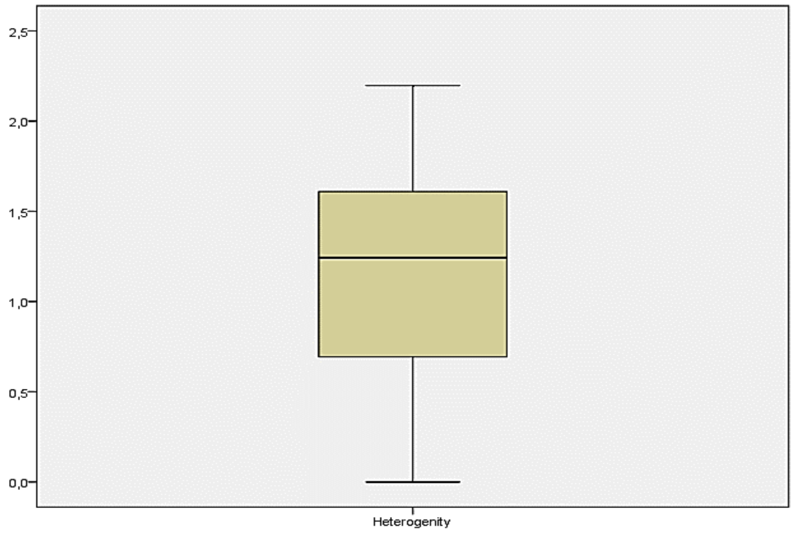


Figure 63: Box and whiskers graphic average of Shannon index for all LCAs analyzed.

5.4.2 – Analysis of the independency between variables

The SPSS Crosstab procedure was used to evaluate independence among categorical variables. Chi-Square test and Cramer's V statistic were calculated to test the independence hypothesis (for $p<0.05$) and to estimate the power of dependence, respectively. Table 27 shows the dependences found among variables considered as relevant (Cramer's V>0.3).

Table 27: Dependence between variables (Chi of Pearson and Cramer´s V).

Points	CROSS OVER	Chi square (≤0.05)	Cramer´s V (≥0.300)
A1	Field * ISO 14040	0.02	0.334
A2	Field * Transportation	0.00	0.392
B1	C.Recycling * S.Boundaries	0.03	0.361
B2	C.Recycling * FoodLosses	0.00	0.341
C	FoodLosses * S.Boundaries	0.04	0.338
D	ISO 14040* Uncertainty	0.00	0.511
E	Transportation * G.P&PG	0.04	0.303

Figures from 64 to 73 show the graphical representation of observed counts per variable.

(A1) Field * ISO 14040

Field and ISO are not independent. There is a relationship between these variables due to the ISO extra points used in the Agri-food field, as can be seen in Figure 64.

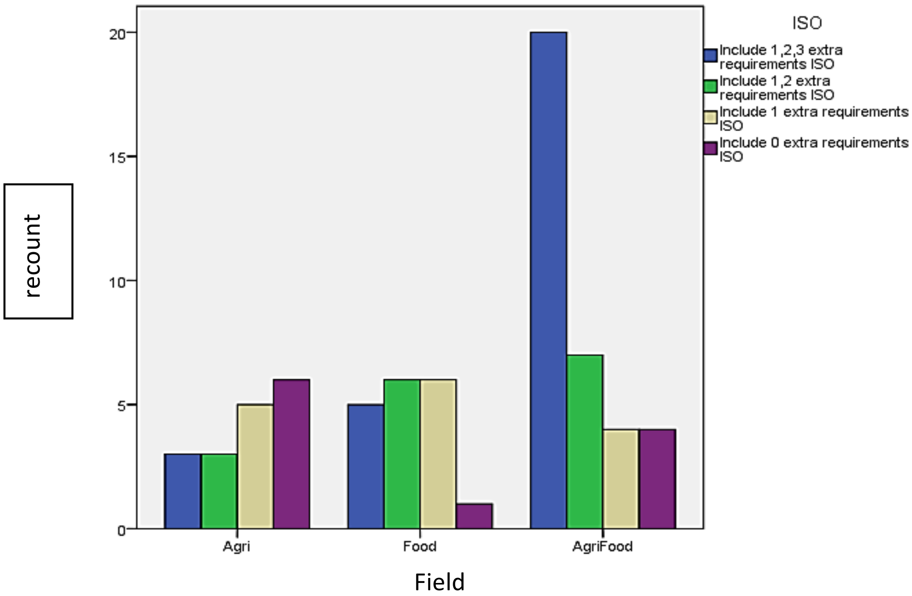


Figure 64: Field frequencies by ISO 14040 levels.

(A2) Field * Transportation

Field and Transportation are not independent. There is a relationship between these variables due to the distribution of Transportation between levels of the Field variable differ significantly, as shown in Figure 65.

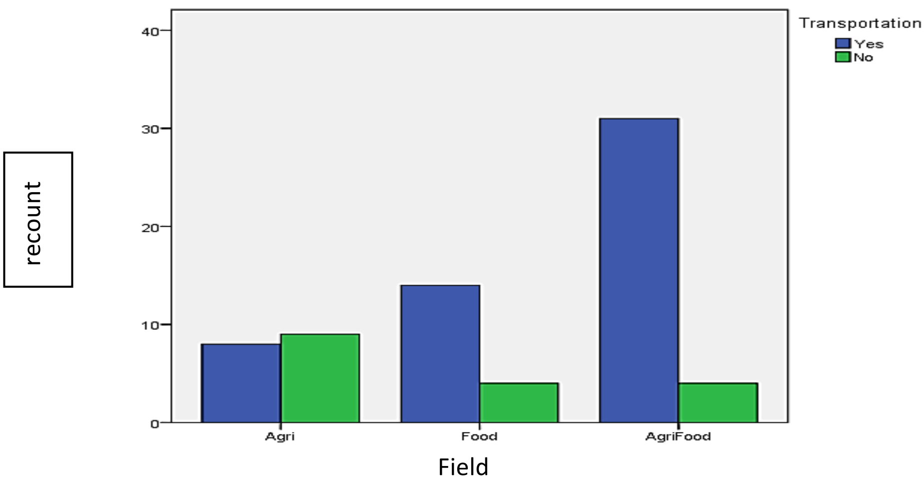


Figure 65: Field frequencies by Transportation.

(B1) C.Recycling * S.Boundaries

Credit Recycling and System Boundaries are not independent. There is a relationship between these variables because the distribution of System Boundaries between the levels of the Credit Recycling variable differs significantly, as it can be seen in Figure 66.

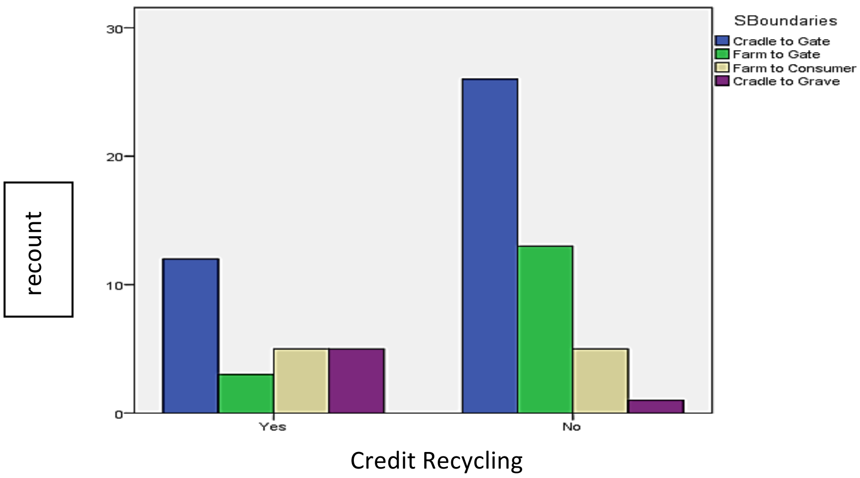


Figure 66: Credit Recycling level by System Boundaries.

(B2) C.Recycling * Food Losses

Credit Recycling and Food Losses are not independent. There is a relationship between these variables because the distribution of Food Losses between the levels of the Credit Recycling variable differs significantly, as can be seen in Figure 67.

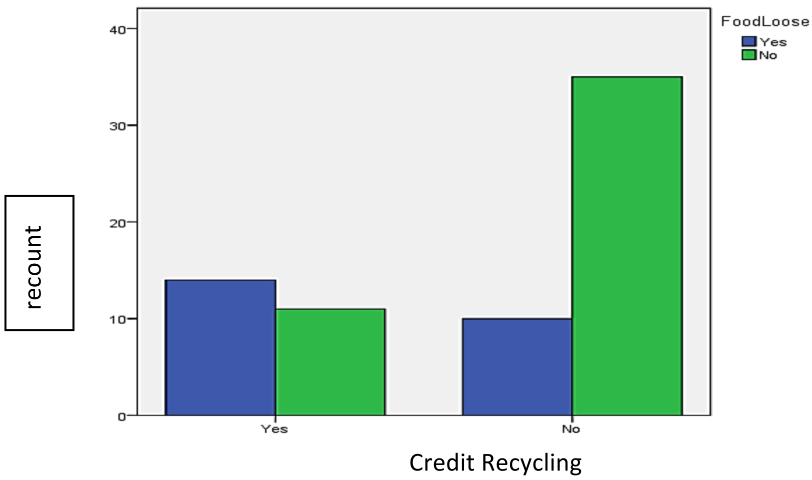


Figure 67: Credit Recycling by Food Losses.

(C) Food Losses * S.Boundaries

Food Losses and System Boundaries are not independent. There is a relationship between these variables because the distribution of System Boundaries between the levels of the Food Losses variable differs significantly, as it can be seen in Figure 68.

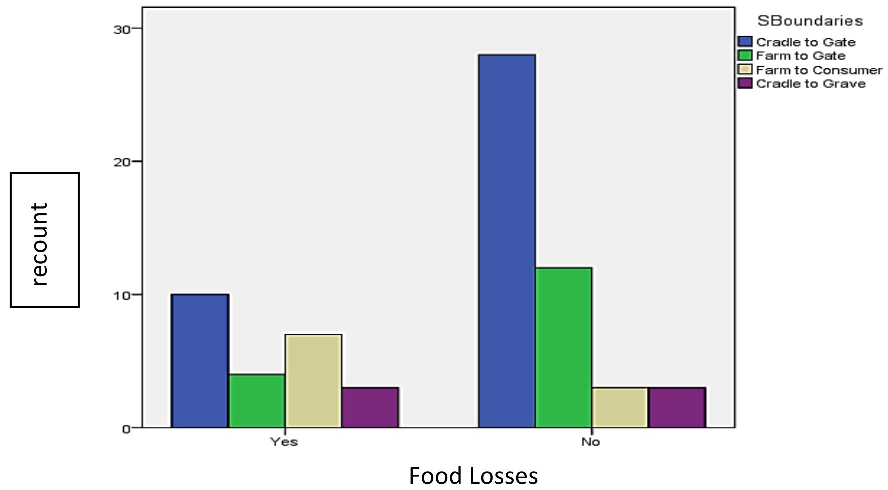


Figure 68: Food Losses by System Boundaries.

(D) ISO 14040*Uncertainty

ISO and Uncertainty are not independent. There is a relationship between these variables because the distribution of Uncertainty between the levels of ISO variable differs significantly, as it can be seen in Figure 69.

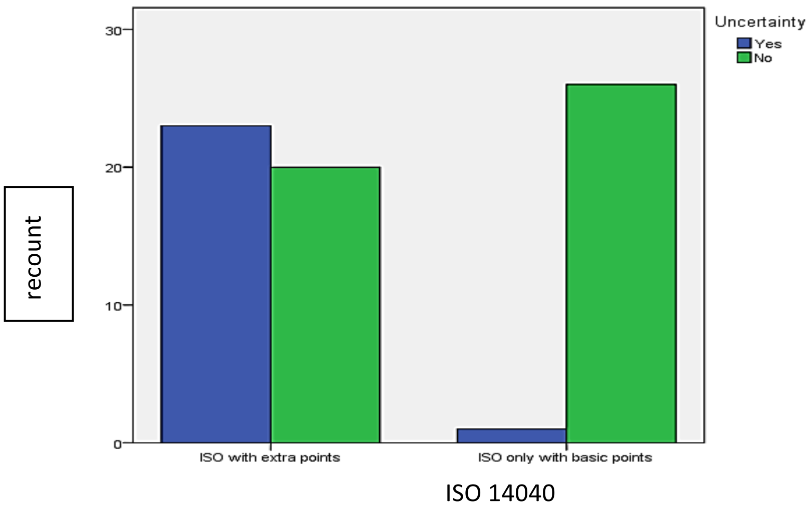


Figure 69: ISO level by Uncertainty.

(E) Transportation * G.P&GP

Transportation and G.P&GP are not independent. There is a relationship between these variables because the distribution of GPD between the levels of the Transportation variable differs significantly, as it can be seen in Figure 70.

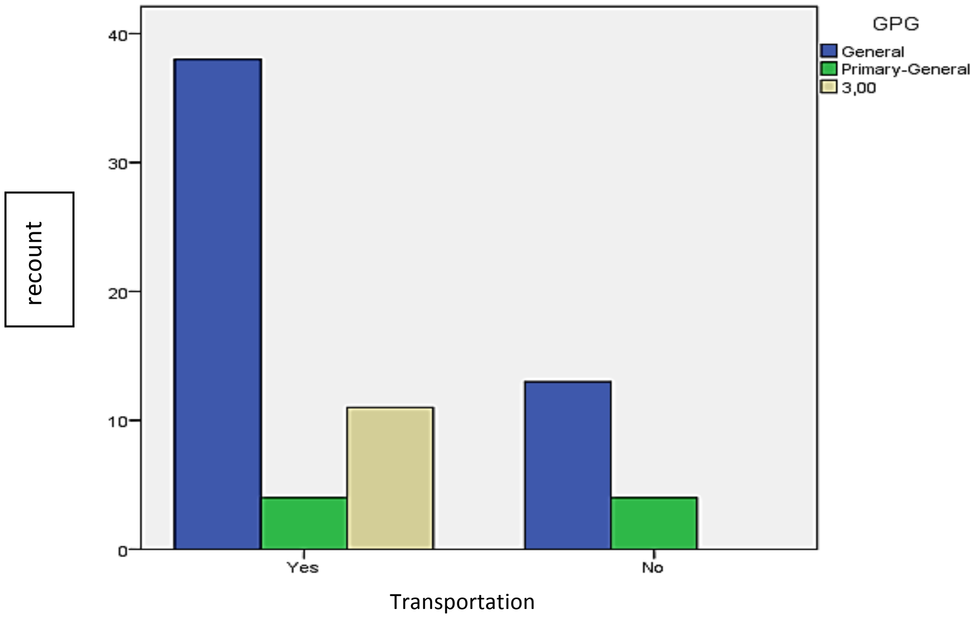


Figure 70: Transportation by G.P&GP database

5.4.3 – Analysis of variance

A one-way ANOVA was calculated with the Shannon index and Equitability as dependent variables and the categorical variables as factors. Statistically significant differences ($p<0.05$) were found in the Shannon index and Equitability for Field variable as factor. Table 28 shows the Levene's test and Table 29 the Anova results. The Tukey post-hoc comparison test shows that differences only appeared between Agri and Agri-food fields, as depicted in Table 30. Figure 76 and 77 shows the Shannon index and Equitability average for each level of the Field variable.

Table 28: levene's test.

Test of homogeneity of variances

	Levene´s test	df1	df2	Sig.
Shannon	,097	2	59	,908
Equitability	,383	2	59	,683

Table 29: ANOVA results.

ANOVA

		Sum of squares	gl	Quadratic mean	F	Sig.
Shannon	Between groups	,765	2	,382	3,108	,049
	Inside groups	7,259	59	,123		
	Total	8,024	61			
Equitability	Between groups	1,320	2	,660	3,891	,026
	Inside groups	10,012	59	,170		
	Total	11,333	61			

Table 30: Tukey post-hoc comparison between Agri and Agri-food fields.

Multiple Comparisons

HSD Tukey

Dependent variable			Difference of means (I-J)	Standard error	Sig.	95% confidence interval	
						Lower limit	Upper limit
Shannon	Agri	Food	-,14232	,12223	,479	-,4362	,1516
		AgriFood	-,28107*	,11482	,045	-,5571	-,0050
	Food	Agri	,14232	,12223	,479	-,1516	,4362
		AgriFood	-,13875	,10269	,373	-,3857	,1082
	AgriFood	Agri	,28107*	,11482	,045	,0050	,5571
		Food	,13875	,10269	,373	-,1082	,3857
Equitability	Agri	Food	-,23934	,14355	,226	-,5845	,1058
		AgriFood	-,37589*	,13484	,019	-,7001	-,0517
	Food	Agri	,23934	,14355	,226	-,1058	,5845
		AgriFood	-,13655	,12060	,498	-,4265	,1534
	AgriFood	Agri	,37589*	,13484	,019	,0517	,7001
		Food	,13655	,12060	,498	-,1534	,4265

*. The mean difference is significant at the 0.05 level.

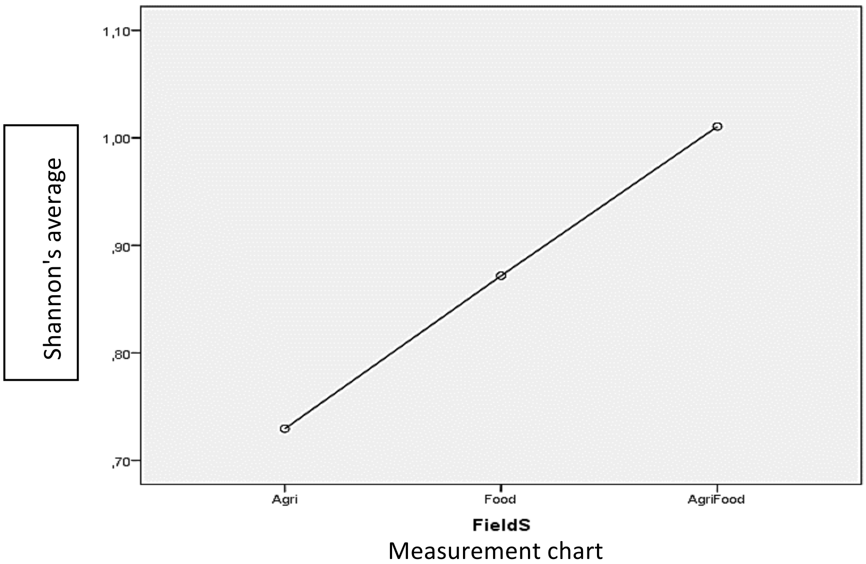


Figure 71: Line graphic representing the correlation between Shannon index and Field.

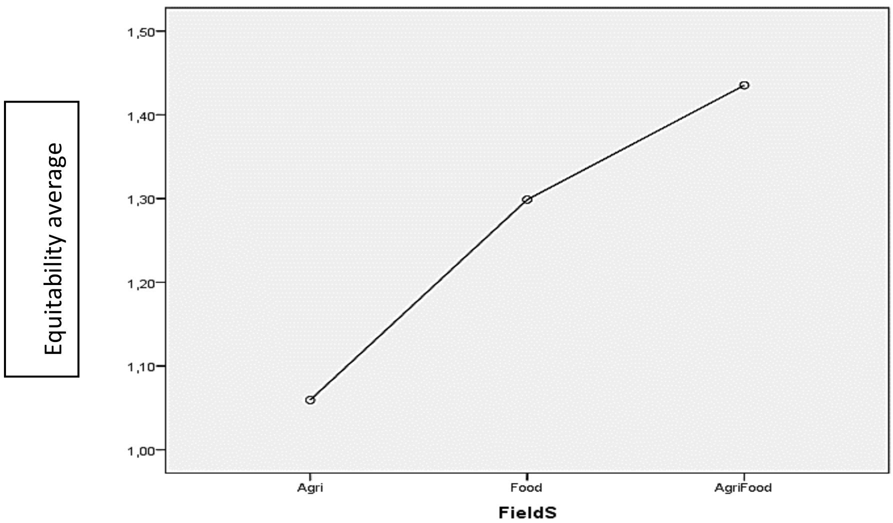


Figure 72: Line graphic representing the correlation between Equitability and Field.

Statistically significant differences ($p<0.05$) were also found in Shannon index for ISO 14040 variable as factor. Table 31 shows the Levene's test and Table 32 the Anova results. LCAs studies implementing ISO extra points have higher values in the Shannon index than those which do not consider such extra points. Figure 73 shows the Shannon index average for ISO 14040 with and without extra points.

Table 31: Levene's test.

Test of Homogeneity of Variances

Shannon

Levene Statistic	df1	df2	Sig.
,399	2	67	,672

Table 32: Anova results.

ANOVA

		Sum of squares	gl	Quadratic mean	F	Sig.
Shannon	Between groups	,848	1	,848	4,287	,042
	Inside groups	13,453	68	,198		
	Total	14,301	69			

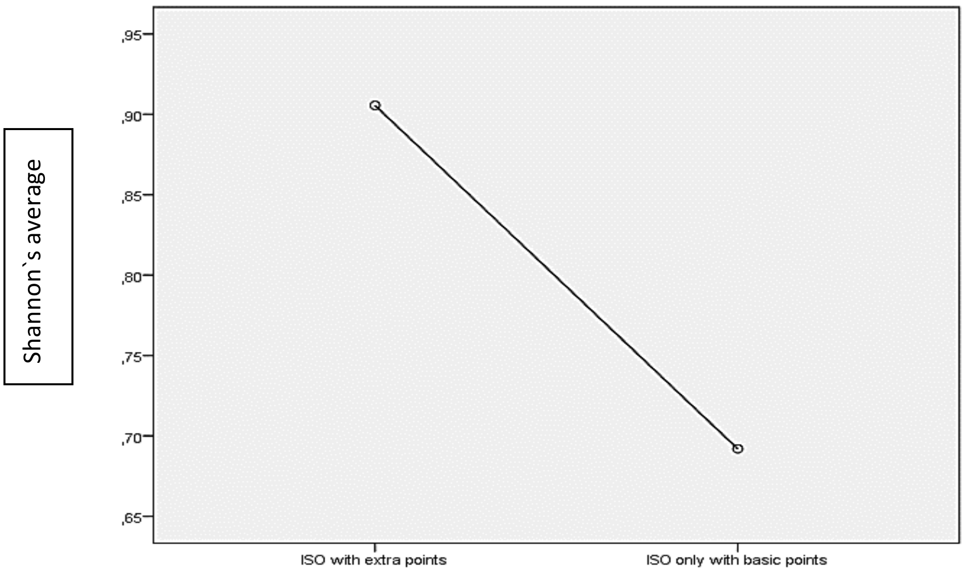


Figure 73: Line graphic representing the correlation between Shannon index and ISO with and without extra points.

5.5 - Clustering evaluation

According to frequencies, distribution and independency among variables, eleven variables were selected as the most relevant to classify LCA studies (see Table 33).

Table 33: Grouping variables

Number of variables	Variables
V1	Field
V2	Packaging material
V3	Primary data vs General data
V4	ISO 14040 settings
V5	Allocation
V6	Credits recycling
V7	System boundaries
V8	Food losses consideration
V9	Transportation impacts
V10	Shannon Index
V11	Equitability

According to the grouping variables, the clustering analysis classified selected LCAs studies in four clusters. Figure 74 shows the clustering quality classification bar with statistical clustering confidence. The bar in the yellow part, ranks the cohesion of cluster classification as acceptable.

Figure 74: Clustering quality classification.

The percentage of cases in each group can be seen in Figure 75. The largest cluster size, represented by cluster two, groups 22 out of the 70 LCAs studies of the sample, and the smaller cluster size, represented by the cluster one, has 12 LCA studies.

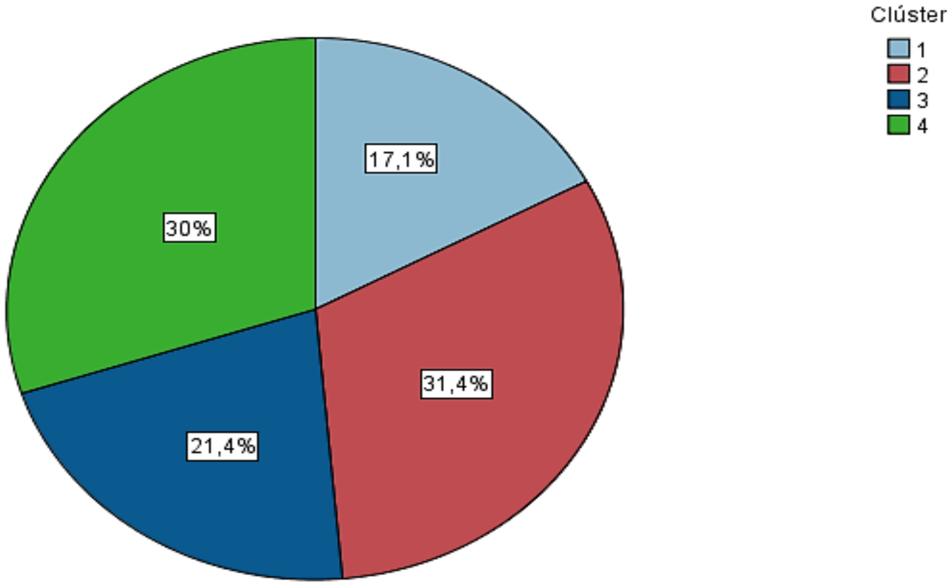


Figure 75: Percentage of cases in each group.

5.5.1 - Importance of grouping variables

The importance of grouping variables is shown in Figure 76. Transportation, Food Losses, Credits recycling, Packaging and Field are the most influent variables when it comes to classify cases in groups. On the other hand, the G.P&GP, Shannon index and Equitability are the least influential variables to discriminate among groups.

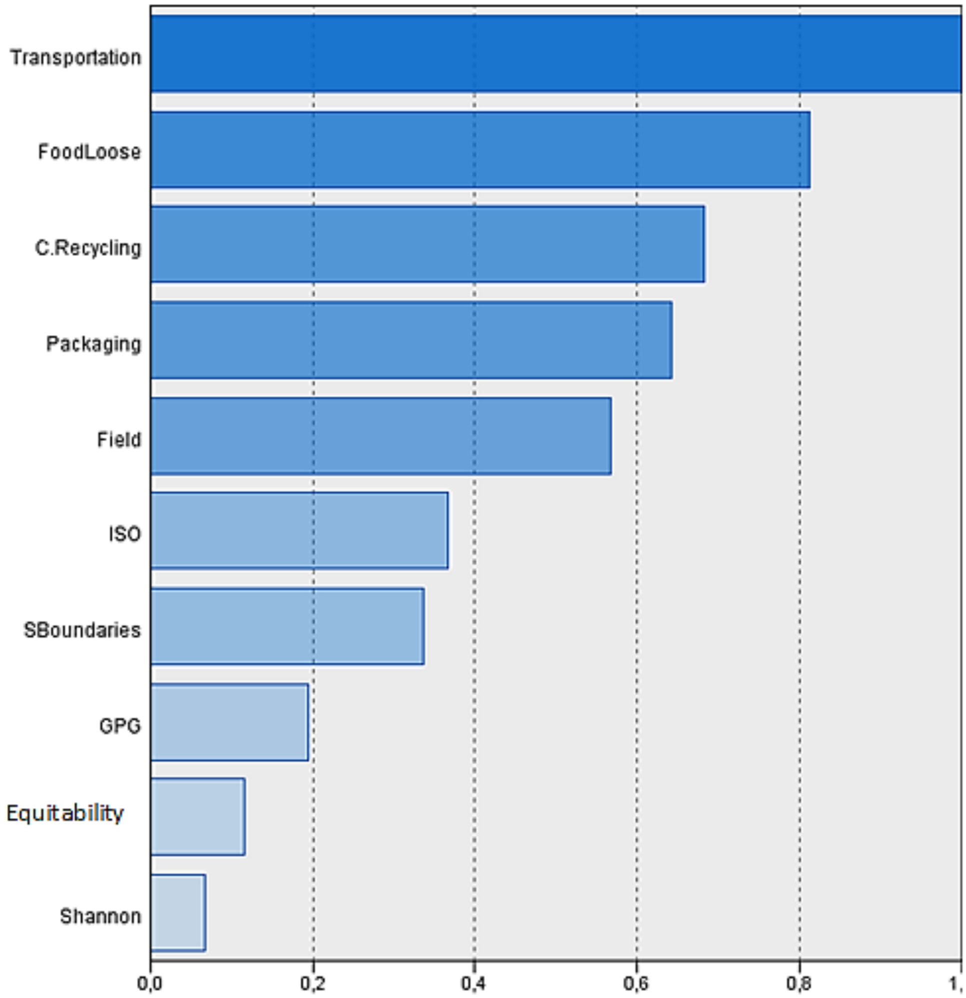


Figure 76: Importance of grouping variables to general clustering classification.

5.5.2 - Importance of grouping variables in each cluster

The most relevant variables to classify cases in cluster two are Transportation, Foodlosses, Packaging and C. Recycling. In the case of cluster four, the most relevant variables are Transportation, Food Losses, Packaging, C. Recycling and Field. In the case of cluster three, these variables are Transportation, Foodlosses and C. Recycling. In the case of cluster one, they are Transportation, Foodlosses, Packaging and C. Recycling (see Table 34).

Table 34: Representation by color and importance of grouping variables in each cluster.

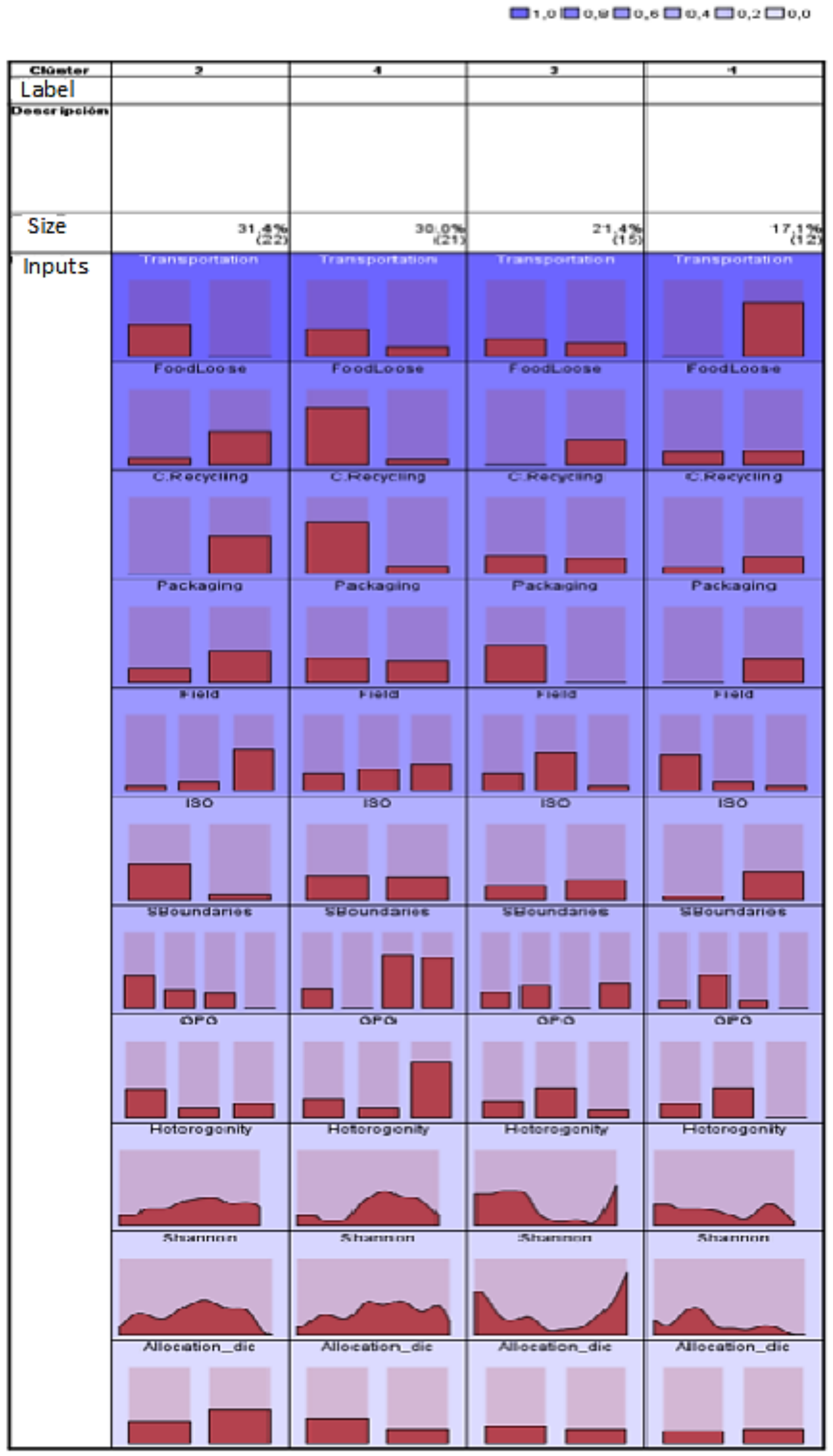
Groupings
Import of Input (predictor)

1,0 0,8 0,6 0,4 0,2 0,0

Cluster	**2**	**4**	**3**	**1**
Size	31,4%	30,0%	21,4%	17,1%
Inputs	C.Recycing	FoodLoose	Packaging	Transportation
	Field	C.Recycling	Field	ISO
	ISO	SBoundaries	FoodLoose	Packaging
	Transportation	GPG	Equitability	Field
	FoodLoose	Transportation	SBoundaries	SBoundaries
	Packaging	Equitability	Shannon	GPG
	Equitability	Shannon	GPG	C.Recycling
	SBoundaries	Allocation_dic	ISO	Shanron
	Allocation_dic	Packagng	Transportation	Equitability
	Shannon	Field	C.Recycling	Allocation_dic
	GPG	ISO	Allocation_dic	FoodLcose

A description with the frequency value at each level for grouping variables can be seen in Table 35. (See appendix 1)

Table 35: General graphic representation of global clustering classification.



5.5.2.1 – Description of cluster 1

Cluster 1 mainly includes cases from the Agriculture field (see Figure 77). LCAs in this cluster generally do not consider the impacts of Transport, Food Losses, Credit Recycling and Packaging. They follow only the ISO basic points; the system boundaries normally used correspond to the farm-to-gate approach, and they use general databases as data sources. Allocation is considered in the impact evaluation.

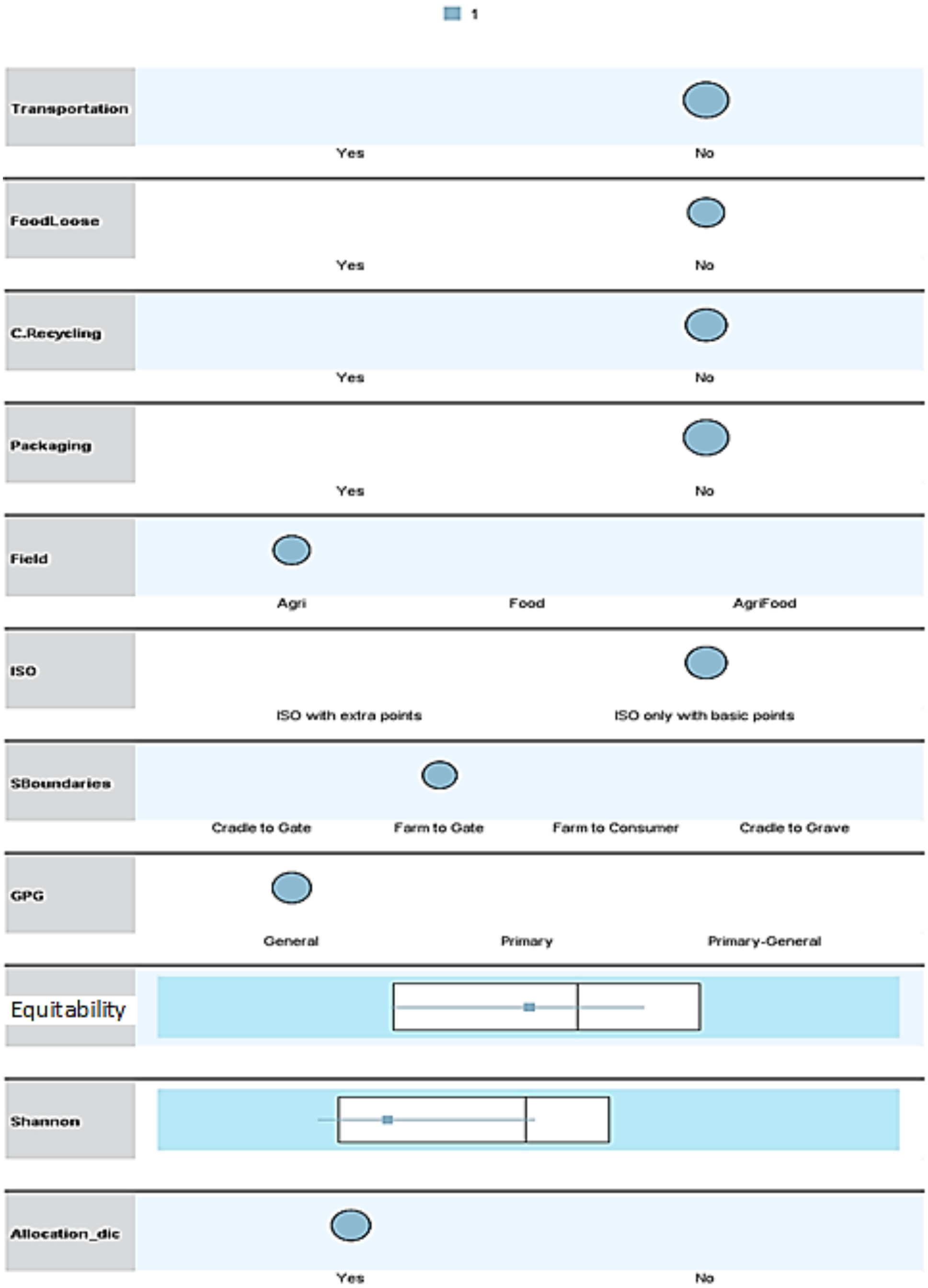


Figure 77: Graphical representation of Cluster 1.

5.5.2.2 - Description of Cluster 2

Cluster 2 is one of the two clusters that appeared in the final cluster solution which field is Agri-food. LCA studies in this cluster do not consider the impacts of Food Losses, Credit Recycling and Packaging. They consider the Transport impact, follow the ISO extra points, the system boundaries normally used correspond to the cradle-to-gate approach and they use general databases as data source. The allocation is considered in the impact calculation, and they reach good values of Shannon index and equitability (see Figure 78).

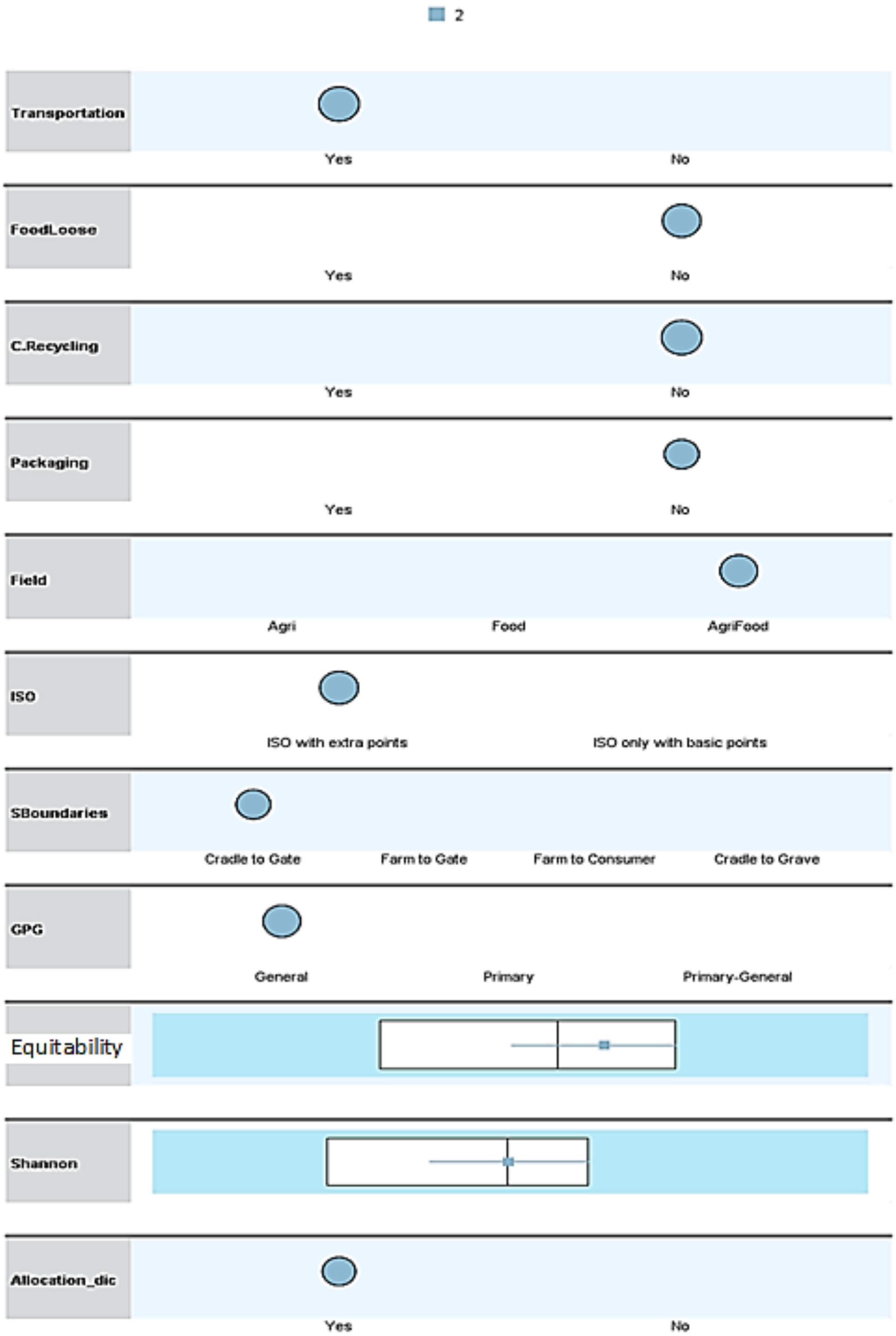


Figure 78: Graphical representation of Cluster 2.

5.5.2.3 - Description of Cluster 3

The Field in Cluster 3 is Food. LCA studies in this cluster do not consider the impacts of Food Losses and Credit Recycling, they consider the Transport and Packaging impact, and follow the ISO extra points. The system boundaries normally used correspond to the cradle-to-gate approach and they mainly use general databases as data source. The allocation is considered in the impact calculation (see Figure 79).

Figure 79: Graphical representation of Cluster 3.

5.5.2.4 - Description of Cluster 4

Cluster 4 is the other cluster in which the most common field is Agri-food. LCAs in this cluster only exclude Packaging impacts, as impacts of Food Losses, Credit Recycling and Transport are considered, in general. Studies in this group follow the ISO extra points; the system boundaries normally used correspond to the cradle-to-gate approach and they use mostly data coming from general databases. Allocation is considered in the impact calculation and they reach higher values in the Shannon index and equitability (see Figure 80). This cluster could be considered as having the highest quality performance standards.

Figure 80: Graphical representation of Cluster 4.

5.6 – Roadmap and good practices manual

5.6.1 – Roadmap

The roadmap defines the practices to be applied when it comes to improve LCA performance in the Agri-food sector, according to the aforementioned clustering results. Once the number of clusters that classifies LCA applications in the sector are known, as well as their weaknesses and strengths, some practices, methods and tools to improve LCA could be defined to be applied in the short, medium and long-term.

Figure 81 shows the selected practices that should be implemented to improve LCA applications in the obtained clusters. The roadmap classifies actions to be performed in the short, medium and long term.

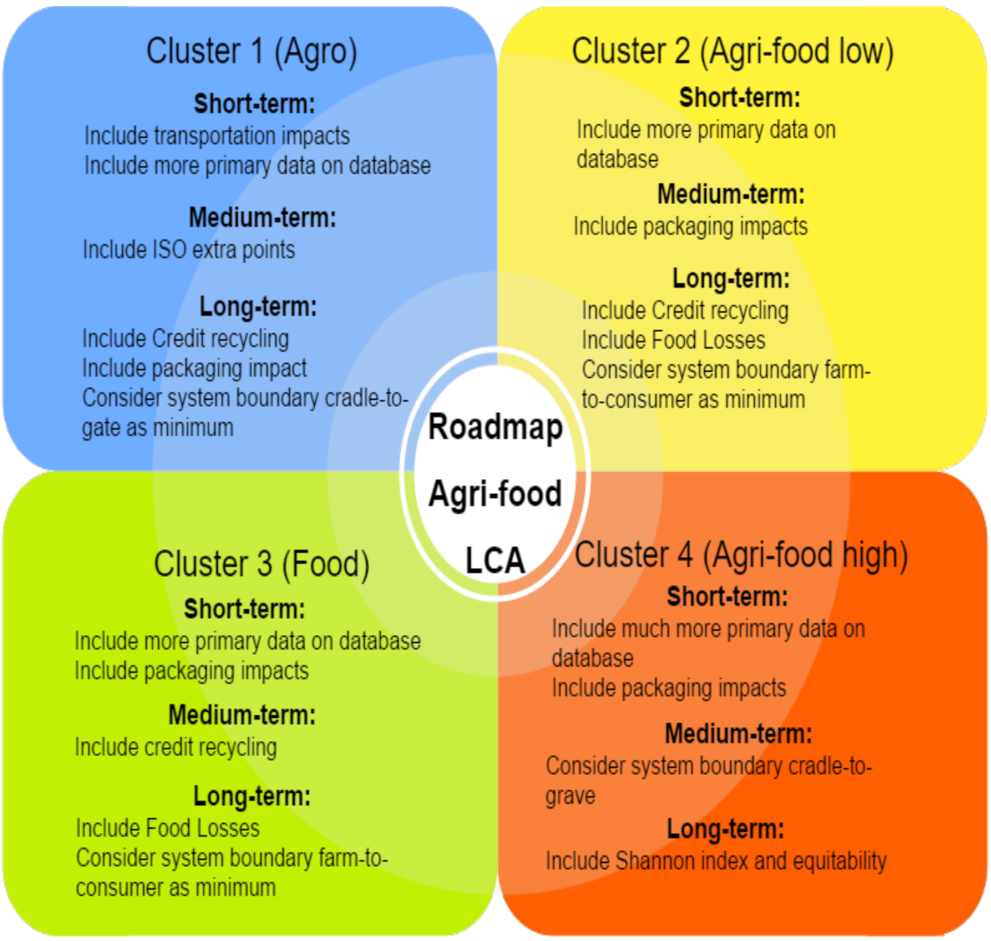


Figure 81: Roadmap proposition to clustering into short, medium and long-term.

5.6.2 – Good practices manual

The good practices manual is the continuity of the roadmap proposition to guide the best application of LCA in the Agri-food sector, improving the current standards achieved by the LCA works analyzed.
Table 36 is based on the FAO template of good practices proposition and summarizes the elements to be considered when it comes to define a new Good practices manual.

Table 36: Good practices manual proposition for Agri-food sector LCAs

Element	Guiding questions	Meaning
Target audience	To whom is this document addressed?	The manual it is addressed to all professionals whose use or develop the LCA tool in Agri-food sector
Objective	What is the aim/objective of these good practices?	To define the practices to be done when it comes to improve LCA performance in the Agri-food sector.
Location /geographical coverage	What is the geographical scope where the good practices are going to be used?	LCA applications around the world.
Introduction	What is the context and challenge being addressed?	The challenge is to find the minimum LCA viable application in the Agri-food sector according to previous defined levels of performance.
Stakeholders and Partners	Who are the beneficiaries or the target group of the good practice? Who are the users of the good practice?	Universities and Research Centers; Consultants; Financial institutions; Governments; Industry Associations; NGOs; and Consumer Associations.
Methodological Approach	What methodology has been used in order to address the initial issue leading to a successful outcome and finally to the good practice?	Classifying LCA works typologies in the sector into groups → Identification weaknesses and strengths of each group → Practices, methods and tools definition to improve LCA belonging to these groups→ Application of these practices and methods in the short-term, medium-term and long-term

Element	Guiding questions	Meaning
Impact	What will be the impact (positive or negative) of this good practice on the beneficiaries?	This list of good practices aim at gradually improving the performance achieved by LCA practitioners in the Agri-food sector.
Innovation and Success Factors	In what way will the good practice contribute to an innovation?	The basic variables to be used according to the previously defined level of performance may guide practitioners to gradually improve their LCA works
Constraints	What are the challenges encountered in applying the good practice?	Challenges may be related to the available resources, different practitioners' objectives (industry vs academy), data sources development and different countries regulations.
Sustainability	What are the elements that need to be put into place for the good practice to be institutionally, socially, economically and environmentally sustainable?	
Replicability and/or up-scaling	What are the possibilities of extending the good practice more widely?	After usage and further critical review of this manual, they could be extending, adapted and replicated to others economy sectors.

5.6.2.1 - Performance levels definition

Beyond the minimum LCA requirements, three suitable levels of LCA application performance were defined according to the selected variables shown in Table 37.

Table 37: Main variables to be used in the LCA levels proposition.

Premises design and facilities		Recommended practices	Objectives
1	Location	To delimit geographical areas to consider in the scope of study.	Identify the LCA geographical scope.
2	Field	Classify clearly the type of boundary to be assessed, if the study will consider agriculture, manufacturing or both.	Identify the type of boundary to be considerate in the LCA´s.
3	Objectives/ Scope of LCA	In this phase define clearly al objectives and scope to be addressed in the LCA.	Define what will be assessed.
4	ISO	Include the maximum of steps defined by ISO, including the extra points.	Identify the ISO level implementation
5	Database	Using primary data when possible. In case you have to use only general database, do sensitivity analysis of information.	Identify the source of data.
6	System boundary	According the selected field, use the broader system boundary possible.	Identify clearly the system boundary of LCA.
7	Transportation	Try to include the transport impact in the studies.	Include transportation impacts.
8	Shannon index	If possible, use the Shannon index to calculate the amount of information used in the study.	To stimulate the use of Shannon index on LCA´s.
8.1	Equitability	Together with Shannon index, use the equitability value of the results to know the heterogeneity of the used input to calculate the each Category of Impacts.	To stimulate the use of equitability according Shannon index results.

Level 1 includes basic variables to consider the LCA application quality as good enough in the Agri-food sector.
These four variables (described in the cluster 1) were selected according to the statistical results of this thesis, as they were mostly included in all the LCA works analyzed.

Level 2 increases the number of items to be considered, including transportation and packaging impacts. In this case, the use of the Shannon index and equitability is a plus to be considered in the study.

Level 3 is the most complete and rigorous level, including transportation and packaging impacts, food losses, credit recycling, the Shannon index and equitability.

Figure 82 shows an infographic with the different performance levels proposition for LCA applications in the Agri-food sector.

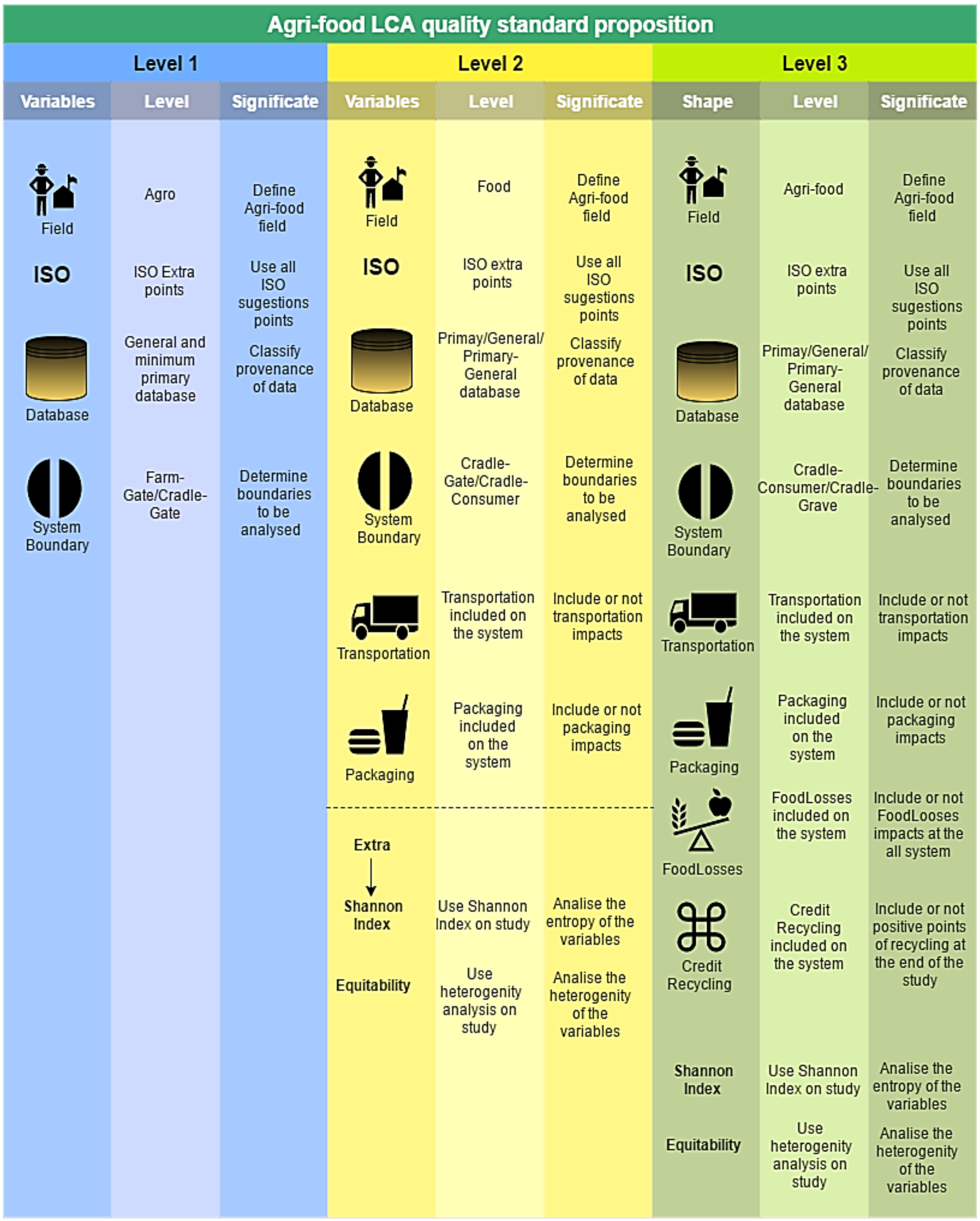


Figure 82: Standard level proposition for the inclusion of minimum variables in the different levels of LCAs in the Agri-food sector.

Chapter 6

Discussion

6 - Discussion

6.1 – Discussion on the people and process assessment (phase 1)

The proposed methodology allowed contrasting the starting hypothesis to fulfill the research objectives initially proposed. The methodology integrated a combination of qualitative and quantitative research approaches. Combining qualitative and quantitative methods leads to some benefits and provides some advantages when analyzing complex questions (Brannen, 1992). The qualitative data provided a deep understanding of survey responses, and statistical analyses allowed finding reliable patterns among responses (McKeganey, 1995). In this line, qualitative analysis allowed identifying the main problems related to data exchange from the LCA's experts point of view. On the other hand, quantitative analysis provided knowledge about the amount of information included in LCA works and the classification of recent LCA works in the Agri-food industry into groups according to a selected number of variables, which provided an overview about the state of the art in this industry.

Over the last decade, LCA applications have undergone significant changes (Hunt & Franklin, 1996), and it seems that it will be the case for years to come (McManus & Taylor, 2015). New regionalized databases will be developed, new impact assessment methods will be designed, and methods for uncertainty analysis will be improved and increasingly used in the very near future (Hetherington et al., 2014). In this line, experts believe that the second decade of the 21st century will be the time for real international LCA implementation (Guinée et al., 2011). At that time, LCA will be enough developed to offer a solid framework able to face challenges from the simplest level (products, sectors and economies) to the full sustainability scope (people, planet, and profit) (IPP, 2010). However, Teixeira et al. (2011), who conducted a systematic survey to determine LCA evolution from the LCA experts' point of view, pointed out that LCA methodologies and practical applications will be divided into two completely different groups in ten years. On the one hand, methodological distinctions which are now made using two approaches (attributional and consequential) to set LCA goal and scope will become more complex, such as hybrid LCA using Input-Output tables (Finnveden, 2008). On the other hand, as LCA is gradually moving away from academic studies to companies applications, there is a more practical and business-oriented side of LCA, searching for simplification without compromising accuracy.

This apparent contradiction about LCA requirements was in part analyzed in this thesis, showing the barriers and differences in LCA requirements between academy and industry, as well as between Brazil and Spain. Differences in information exchange in both countries were analyzed and the social network analysis from LCA stakeholders in those countries was also performed. Results made clear that industrial and academic stakeholders had a better relationship in Spain than in Brazil. This can be justified by the cooperation existing between the academia and the industrial stakeholders, leading to an increasing use of LCA in the Spanish industry. The good relationship between academia and industrial stakeholders is one of the keys that place Spain among the top 5 countries in LCA publications worldwide (Qian et al., 2015). These publications mainly come from universities, but the data exchange between industries and academy is essential to allow experts to publish.

Getting data is one of the main difficulties to perform a Life Cycle Inventory (Werner, 2005). The lack of national databases is a bigger problem for academics from Brazil than from their counterparts in Spain. It is clear than the access to data is easier in Spain than in Brazil, probably because data measurement is done more systematically and communication between stakeholders is higher.

Other important issue regarding data quality is that most experts from academia and industry in both countries compare their data with others databases and scientific publications before using it. An important difference between Brazilian and Spanish experts from academia is that academics from Brazil have more trust in the information directly coming from companies than Spanish ones do. In Spain, academics use more sensitivity analysis in their LCAs than in Brazil, when the opposite should be the trend due to the difficulties to find reliable data in Brazil.

In the case of the Spanish group, the technical experience in the sector is very important when it comes to consider the quality of collected data. This aspect was mentioned in both academia and industry. However, only the industry group from Brazil considered the technical experience important to classify the quality of data.

In LCA, data sharing normally is accompanied by barriers and problems. In the Brazilian academia group all the interviewed claimed that industry has fear to share their data, but the industry does not consider having fear to do it. This behavior shows that communication and points of view between these groups are very different in Brazil. In Spain the academics do not consider that industry has fear to share data, but most of industrial LCA experts think so, showing that there

are differences in requirements and in the behavior of the stakeholders in Brazil and Spain.
Other important consideration differently assessed in these countries is that experts from industry in Spain worry about consumers misunderstanding results, even when positive results are given. According to them, even if the results of a study are positive comparing with other products, the consumer could not understand and might interpret negatively an environmental improvement. In Brazil, this topic was not cited in any group.

Finally, when comparing in terms of centrality the results of social network analysis between Brazil and Spain, the results are similar in both countries. In both cases the centrality of data focuses on Universities; but there are more universities in Spain than in Brazil. This might be because the communication between LCA stakeholders is more fluid and close in Spain than in Brazil. Industrial managers and academic staff exchange data more intensively in Spain. However, the creation of the Brazilian LCA industrial network three years ago could be a good step for improvement.

6.2 - Discussion on the information quality and quantity of assessment in the Agri-food sector (phase 2)

LCA is currently used in many industrial sectors, but this thesis focused on the use of LCA, its applications and results in the Agri-food industry because of its international relevance, worldwide impact and especial sensitivity because the product is being ingested.

Schmidt (2015) states that in the Agri-food industry there is a lesser quantity and quality of environmental studies than in other industrial sectors, as for example in automotive and construction industries. So, despite its quest for sustainability (Bremmers et al., 2007), the Agri-food sector needs to enhance the credibility and quality of the provided information (Simnett et. al, 2009). This may be especially critical in the agriculture field in comparison with other fields analyzed in the present thesis.

According to Araya et al. (2015), 32.9% of companies in the Agri-food industry made some environmental evaluation of their products compared to 42.2% made in other industries. This is consistent with GRI data (2013), which showed that the percentage of reports in the food and beverage industries was below the general percentage. They found a significant association between this industry and the adoption of tools for environmental assessment. Agri-food companies were less likely to adopt those tools than companies from other sectors.

Araya et al. (2015) analyzed agriculture, food and beverage industries and found that 15.1% of companies from the agriculture sector and 37.7% of those from the food and beverage industries made some environmental analysis. Agriculture companies were less likely to ensure their sustainability reports. However, differences observed between the food and beverage sectors and other industries were not significant. This is in line with the cluster results of this thesis, where the agricultural cluster has the biggest lack of LCA studies both in quantity and quality.

Morais et al. (2016) described that LCA oriented to Agri-food products requires modifications in the classical methodology, to guarantee efficient and reliable impacts assessment. Agriculture uses natural resources differently than industrial processes; thereby resources and raw materials, waste production, technologies and the environment interact to each other in a different way. Consequently, raw materials analyses, utilization and final destiny, functional units and impact assessment should have a different approach and methodology, as have been proven by the comparison results between Brazil and Spain in this thesis. Different countries have different realities, requirements, needs and perspectives in this sector.

As described above, the use of the LCA tool in the Agri-food industry is growing, but the specific applications and requirements are neither clear nor standardized for this sector. In this research, one of the goals was the selection and classification of variables to be considered to perform LCA works in this sector. After analyzing 70 LCA works in the Agri-food sector around the world, a checklist was created with the most used variables, with the aim of analyzing and classifying these works in terms of quality and quantity of the included information. Then three levels of quality performance were provided according to the inclusion of three different subsets of these variables. Despite the fact that this proposal should be tested in further works, it can be said that it would be useful as a first attempt to standardize LCA works in the Agri-food sector.

One of the important characteristics of agricultural LCA is the use of multiple functional units. The commonly used functional units are mass of final products (kg), energy or protein content in food products (kJ), area (ha), land use and unit of livestock. Although the use of LCA in the Agri-food industries is rapidly increasing, there are considerable inconsistencies existing among the studies. The conventional agriculture uses a greater amount of fertilizers and pesticides compared to the organic agriculture, but organic agriculture requires more arable land. Genetically modified (GM) agriculture reduces emissions from herbicide manufacture, transport and field operation compared to the conventional agriculture. Therefore, the multiple functional units help interpreting and understanding the environmental burden, productivity and farm income better. In addition to the functional unit, in this research many other factors were identified that might contribute to some extent depending on the analyzed field. An example of this is the consideration of packaging on an LCA study. Usually in "Agro", LCAs packaging is excluded of the system because the most important factor to include is the relation with the product's weight. Moreover, other controversial factor is the consideration of transportation in the LCI phase.

Herein, every variable considered as important to include in an LCA study will be discussed.

Field

The field is considered as an important starting point of LCA studies. This research divided the Agri-food industry into three different groups or fields: Agro/Food/Agri-food. There is an important correlation between field definition and system boundaries as Vinyes et al. (2015) started to discuss. However, in this thesis no correlation between these variables was found, as shown in the results of the dependence variables analysis. The field presented significant dependence with ISO and transportation, but this was not the case with systems boundaries.

System Boundaries

System boundaries are another differentiating aspect, since conventional LCA usually includes a cradle-to-grave approach, while Agri-food studies are normally restricted to cradle-to-gate phases. Distribution after the farm, consumer processing and final destination display high uncertainty (Hayashi, 2011) and are typically neglected. This choice may be acceptable since agricultural production is often the hotspot in the life cycle of food products (Roy et al., 2009) and this is in line with the distribution among fields of the system boundaries shown in the obtained clusters.

The situation of the exclusion of many post-harvest steps that are considered important is very common in Agro LCA studies, including packaging and transportation. Good system boundaries definition should include those variables when suitable. In this case, depending of the field to be assessed, these variables have to be considered in the system.

Different source data

Life Cycle Inventory or the collection of data is probably the most important step of LCA, but in major cases is the most difficult step as well. The information could come from the original data measured at companies or from commercial databases (from the same country or mostly from others countries). Regarding the sample of LCA works analyzed, Ecoinvent is the most used database. In Brazilian studies, the reality or compatibility of data is very different because most of the available data is usually based on information pertaining to the Swiss Agri-food industry. Thus, depending on the quantity of external data available to complement primary data, a sensitivity analysis should be performed trying to fit data to the local reality.

Packaging material

Depending on the field, packaging could have more or less impact. As stated by Tobler et al. (2011), consumers seemed to attribute more environmental impact to packaging than LCA does. Most studies do not consider packaging among product impacts, but in many cases, like in food manufacturing, the use of plastic or metal is noteworthy and it should be considered, along with the transportation impact. This should be applied in all fields cited above.
"Considering the general life cycle perspective of a food package offers a more holistic consideration of what chemicals may end up in the food due to packaging that were not intentionally added package ingredients" (Henningsson et al., 2004)

In previous notes from Henningsson et al. (2004) they consider packaging a fundamental element of almost every food product and a vital source of environmental burden and waste. The fact that packaging isolates food from factors affecting loss of quality such as oxygen, moisture and microorganisms, and provides cushioning performance during transportation and storage could increase its use over time. The packaging of food products presents considerable challenges to the food and beverage industry. On the other hand, minimizing and modifying both primary and secondary food packaging present an optimizing opportunity for these industries (Ajinomoto Group, 2003; Hyde et al., 2001). In agreement with these authors, packaging should be included in any application field.

The packaging system production stage is reported as the principal cause for major impacts. Increasing recycling rates and reducing weight in the primary package are environmentally more efficient measures (Ferrão et al., 2003). In the case of the beverage food industry, according to Hospido et al. (2005) the production and transportation of packaging materials contribute to one-third of the total global environmental impact of the life cycle.

Considering the three divisions of “Field” made in this thesis, “Agro” is the sector that less considers packaging in their assessment. The reason of this could be that packaging weight is not relevant, when comparing it with the product’s weight.

Linking the previous discussion, correct field, objectives and scope selection for an LCA is considered important to determine packaging weight impact. As an example, according to a study about meal production impact from Pelletier et al. (2007), an average meal served in a canteen in Sweden, produces an average climate change of 4.1 kg CO_2-eq. The agricultural production step is responsible for 60% of the emissions, processing for 8%, transport for 5%, canteens operation (cooling, cooking, etc.) for 25% and packaging only for 2% of emissions. The point of view of this study is focused on the agricultural impacts, however, according to this thesis critical review, packaging impact should be considered higher in any field of Agri-food LCAs

ISO 14040 settings

According to section 6.1 of the ISO 14044 standard, the following items have to (“shall”) be considered during any critical review:

1) The data used have to be appropriate and reasonable in relation to the goal of the study;

2) A sensitivity analysis has to be used with data coming from a general database;

3) The used methods to carry out the LCA have to be consistent with this International Standard and consider the maximum of extra points propositions;

4) The interpretations reflect the limitations identified and the goal and scope of the study; and

5) The study report is transparent and consistent, and it should be published if possible.

Most of the analyzed LCAs consider ISO 14040 as a reference standard, but only few consider the extra points.

Basic points of ISO 14040 standard are considered: a) goal and scope definition of the LCA, b) life cycle inventory analysis (LCI) phase, c) life cycle impact assessment (LCIA) phase and d) life cycle interpretation phase.
The extra points referenced are: a) reporting and critical review of the LCA, b) limitations of the LCA, c) relationship between the LCA phases, and d) conditions for use of value choices and optional elements. (ISO, 2006).

Klöpffer and Grahl (2012) stated that it is important to include a critical review (one of the extra points proposed by ISO) in LCA, and proposed some guidelines to be considered:

- Removing contradiction concerning the "stakeholders" and rename the review according to 14040, 7.3.3 and 14044, 6.2 into "review according to the panel method".
- Better defining the "comparative assertion"; draw a line between (academic) research and competitive industrial management (including product promotion, etc.).
- Creating a better awareness of the standards outside industry, consultancy and regulatory organizations.
- Avoiding any kind of unnecessary bureaucratic burdens.

Finally, authors recommended installing interactive rather than "a posteriori" critical review to all commissioners of comparative LCAs. They also remark the results should not be used for any unfair marketing activities.

Impact categorization method

The magnitude and significance of environmental costs associated with specific life cycle activities in the Agri-food industry are identified during the Life Cycle Impact Assessment (LCIA) stage (Pennington et al., 2004). This is achieved by quantitatively expressing the results of Life Cycle Inventory (LCI) using impact categories (classes representing environmental issues of concern) and their input diversity (quantifiable resources/emissions/substances or compounds representing each impact category) (Guinée et al., 2001).

ISO 14040 standard defines both mandatory and optional elements of the LCIA framework. Mandatory elements are: the selection of impact categories, category indicators and characterization models; the assignment of LCI results (classification); and the calculation of category indicator results (characterization). Optional elements are: calculation of the magnitude of category indicator results relative to reference information (normalization); grouping (clustering); weighting (further definition of hierarchy of impact categories and/or variables); and data quality analysis (sensitivity analysis) as described by Guinée et al. (2001). However, in this thesis it is suggested to include some basic optional elements to carry out an LCA, following the definition of proposed quality levels in the good practices manual.

Food losses contextualization in LCA applications

In the critical evaluation of the 70 LCA studies in the Agri-food industry, variables were identified that are almost never considered in the assessment and system expansion (if applicable), the Food losses in this case. As a result of a deep research about this issue, other views were identified. Firstly, two classifications were identified after a scientific literature analysis: (1) Food Losses (FL) and (2) Food Waste (FW), limiting studies comparability and the integration of their results into a common strategy for reducing Food Losses (Corrado et al., 2016; Williams et al., 2015; FAO, 2014; Ostergren et al., 2014).

FAO (1981) defined FW as the wholesome edible material intended for human consumption, lost, degraded or consumed by pests. Stuart (2009) included to the cited FAO definition, the fraction of edible food that is intentionally fed to animals and the by-products of food transformation that are diverted away from human consumption. The characterization and classification of by-products will be discussed below, but it is important to cite that by-products have not been considered in this research. Smil (2004) added to the aforementioned definition of FW, the over-nutrition, defined as the gap between energetic consumption and human needs.

FAO was a pioneer in proposing to harmonize definitions and terms related to FL and FW within the Global initiative on food loss and waste reduction (FAO, 2011b) through a framework of food losses (FAO, 2014b). The discussion about Food Losses definition is not new, and this FAO document was intended to improve data collection, data comparability and evidence-based regulatory and policy decisions for FL prevention and reduction. According to FAO (2014b), FL is "*the amount of food intended for human consumption that, for any reason is not destined to its main purpose"*.

Within LCA studies, FL definition has been rarely reported, apart from studies where the focus was specifically on Food Losses (Heller & Keoleian, 2014). Eberle and Fels (2015) also suggested adopting the FAO (2014b) definition as a basis for LCA studies, mainly in the Agri-food industry. However, this definition was conceived to be generic enough to be applied to a broad range of contexts. Therefore, it is necessary to analyze additional aspects of FL in order to move towards a systematized use of this definition within LCA, to avoid interpretation problems. Many interpretation problems could be linked with bad Fields separation, justifying the inclusion of this variable in the checklist proposed in this thesis. Figure 83 shows an example of official data from FAO representing the percentage of Food Losses in the life cycle of fruit, vegetables and cereals around the world (Figure 83).

Figure 83: FAO statistical example of food losses in the world (From: FAO 2014b).

The inclusion of Food Losses in the LCIA is very sensible because it is difficult to input the impact of bad education or consumers' management in the LCA of a given product, but anyway the influence of consumer behavior on the LCA results has been found to be important in LCAs. The life-cycle use stage of food products should not be overlooked in LCA studies. It is important to include food losses in the entire environmental assessment and not only in the usage phase. Moreover, end-of-life data is required for modeling waste disposal emissions in more detail. This discussion is controversial and broader and it is not the main focus in this thesis, but it can be considered as an important variable to be analysed in further studies in Agri-food sector.

Credit Recycling

There are many policies to manage the improvement of the recycling system, differing among countries. Recycling systems in Brazil and Spain are different. Both urban waste collection and the recycling system implementation in Brazil are very poor. This fact makes LCA results to be different in each country. Nevertheless, in most cases of the studied sample (45 of 70), credit recycling is not considered because, as cited above, in some cases packaging is deemed to have a residual impact on the LCA. In fact, considering packaging impact in the "agro" field could be residual compared to the total product weight, but in the case of food manufacturing, as for example the traditional "Spanish Ham" that uses a big quantity of plastic to conserve its quality characteristics and to be commercialized, the impact of packaging grows in importance. The food industry is increasingly using packaging to deliver its products. Thus, credits recycling should be included in LCAs, especially in Food and Agri-food fields.

Input diversity: Shannon index and equitability

In the classification of environmental impacts during the Life Cycle Impact Assessment (LCIA) stage, the Life Cycle Inventory (LCI) is an important stage that uses impact categories and their associated category indicators or input diversity to quantify resources, emissions and compounds/substances representing each impact category (e.g. Guinée et al., 2001; Pennington et al., 2004). The optional compounds to be included on the system are defined by the calculation of the category indicator results' magnitude relative to reference information or normalization; weighting; clustering; and data quality analysis of each case study (Guinée et al., 2001).

The impact categories and the specific input diversity of each one are very vast, and depend on the scope and nature of the study. In the Agri-food LCAs, the ILCD identified the most common impact categories used, some examples can be acidification, climate change, human toxicity and ecotoxicity. Each impact category has many compounds that take part in its formulation, and can be considered or not in the LCA study. In this regard, the Shannon's diversity index was calculated to measure the entropy of inputs used in each impact category considered in the analyzed LCAs sample. At the same time, equitability was also calculated to measure the number of compounds balanced or not among impact categories. A wide range of Shannon index values were found among LCAs works, because there was a big difference in the number of impact categories considered for each case. Equitability was also unbalanced among LCAs works, because the number of considered compounds varied among impact categories calculated in each LCA.

This index is normally represented as H and is expressed with a positive number, which in most natural ecosystems varies between 0.5 and 5, although its normal value varies between 2 and 3; Values below 2 are considered low in diversity and higher than 3 are high in diversity of species. It has no upper limit or in any case, it depends on the base used for logarithm calculation.

Shannon index values achieved by the sample of LCAs are by far below these ecosystems thresholds. The percentiles P95, P75, P50, and P25 are 1.56, 1.17, 0.94 and 0.45, respectively. Thus, in LCAs studies Shannon index values under 0.45 should be considered as poor, values between 0.46 and 0.94 should be considered as acceptable, values between 0.95 and 1.17 should be considered as good, and values above 1.56 should be considered as excellent. Obviously, these findings may be somewhat limited by the number of LCAs analyzed. In any case, they might serve as a baseline to be used as standards to compare new works with. Further research seems necessary to define more accurate and reliable thresholds in the future. However, it is noteworthy that the results of the Anova analysis show that LCAs belonging to the Agri field category reached lower Shannon index values than those belonging to the Agri-food category. These results are in line with the quality performance achieved by the clusters grouping Agri and Agri-food LCAs, as the quality performance achieved by the Agri cluster is lower than the quality performance reached by the Agri-food clusters. In this sense, LCAs considering ISO 14040 extra points also reached higher Shannon index values than LCAs that only considered basic points. Puting all together, it could be said that the calculation of the Shannon index and equitability might lead to a better comprehension of the quantity and quality of data included in LCAs.

Analysis of independence between variables

Economic, social and environmental variables are normally considered in LCAs (Whenzel, 1998). However, as above discussed, another kind of variables has been used in the present work. Despite the fact that there was some dependence among the selected variables, the result of Chi-square analysis between variables only showed a significant dependence in seven couples of variables (involving eight variables out of 20), so it can be said that they are appropriate to evaluate LCA performance. Variables as Field, Credit recycling, System Boundaries, ISO 14040, Food losses and Transportation showed dependences with two variables, but, excluding ISO 14040 and System Boundaries, all of them are the most influential when it comes to classifying LCAs in the Agri-food sector in groups. Thus, the validity and consistence of such variables to classify LCAs seems to be proven. In any case, more studies of this type in other industrial sectors seem necessary in order to verify their validity in a broader sense.

Clustering

Cluster results classified the quality of 70 LCA studies in four clusters. Cluster grouping cases coming from the Agriculture field (cluster 1) showed the lower quality performance. The lack of a firm regulatory policy, the difficulty of finding the data or its non-existence could be some of the reasons.

Cluster three (Food field) showed a medium quality performance. Food LCAs tend to limit the system boundaries to the facility gate and, in general, do not include transportation, consumption and final destination. Such limitations could be one of the reasons to limit the quality classification of this cluster.

Clusters two and four grouped LCAs from the Agri-food field category. Both of them have the best quality performance, altough they can be divided into two quality groups. The low quality cluster (cluster 2) dismisses important variables such as food losses, packaging and credit recycling. By contrast, high quality Agri-food field cluster (cluster 4) considers all of these variables, only excluding packaging in its studies.

Clustering results are coherent because in the Agriculture field, many important variables considered important in this research are not commonly used in the LCAs studies. However, the Agri-food field is more complete because the system boundary is broader and includes more information quantity. The Food field LCAs are intermediate, presenting a good quality but not in the same level as those of the Agri-food field.

Instead, inside the plant, the manufacturing process is much more controlled and laws are more restrictive than in the agricultural system. So, for this reason, the renovation of requirements and threshold of LCAs in this sector should be discussed and clustering could help this process, improving the new standards regulation to balance the future studies.

6.3 – Roadmap and good practices manual (phase 3)

LCAs clustering shows its classification according to the main variables considered in this thesis. Regarding each cluster weaknesses and strengths, a roadmap is proposed to guide LCAs improvement taking into account three timescales. Short-term actions, to be performed a soon as possible, as they are critical to guarantee a basic quality level, medium-term actions, to be performed to improve the basic demands of LCAs, and long-term actions, which include extra points and actions to be performed once experts overcome previous weakness to achieve the best quality performance.

In this line, the roadmap action will be described according to each group as follows:

Group 1: the inclusion of transportation impacts and the use of more primary data on the LCA database in the **short term** may help improve current quality standards. To solve some problems in the **medium-term,** actions such as the consideration of the ISO 14040 extra points could be helpful to improve LCA results. Finally, the inclusion of credit recycling on the system, packaging impacts, as well as setting cradle-to-gate as the minimum system boundary are the guidelines to improve LCAs in the **long-term**.

Group 2: the use of more primary data on a database to calculate impacts in the **short-term** seems to be necessary. Also, the inclusion of packaging impacts in the study since the food manufacturing process seems important in the **medium-term**. Finally, the inclusion of credit recycling and food losses, as well as setting farm-to-consumer as the minimum system boundary are the guidelines to improve LCAs in this cluster in the **long-term**. These actions could improve the standardization and quality of the LCAs in the future.

Group 3: To solve the most critical limitations in this group in the **short-term**, more primary data should to be used in the database and packaging impacts should be included. The **medium-term** actions in this case are the inclusion of credit recycling in the system. Lastly, the **long-term** actions should be the inclusion of food losses in the system and, linked with the consideration of system boundaries, setting farm-to-consumer as a minimum in the manufacturing food group.

Group 4: To solve deficiencies of this cluster in the **short-term,** more primary data in the database should be included, even though some LCAs in this group already use good primary data, as well as the inclusion of packaging impacts to calculate the weight of these impacts in different cases. The **medium-term** action is the consideration of a complete system boundary (cradle-to-grave). Finally, the **long-term** actions to be applied are the inclusion of the Shannon index and equitability in the study in order to include a classification of information quality and quantity for the study, according to the thresholds stablished in this thesis.

In line with the obtained results and the proposed roadmap, the proposition of the good practices manual could help guide further LCA works. As can be seen in the results section of this thesis, see Table 37, a good practices manual focused in the Agri-food sector is presented.

The good practices manual is proposed as a continuation of the roadmap proposition where the main actions in each cluster are described, in order to achieve the best quality in this sector's LCAs. The manual guides the best application of LCA in the Agri-food sector, by including the current standards achieved by the LCA works analyzed in this thesis.

The manual proposition was based on the FAO template to guide initiatives like this thesis to bring value and new knowledge to the Agri-food sector.

The manual contains eleven elements and each has its own guide questions and meaning in order to encourage the use of the clustering classifications and roadmap proposition in this research.

Finally, three levels of quality performance for LCA in the Agri-food sector were defined (see Table 38). Level 1 is the low quality level that presents the minimum variables to consider, apart from the basic requirements established in the LCA literature. The minimum points to be considered are a good definition of the field "Agro", the consideration of ISO extra points, the use of a minimum amount of primary data (what the minimum is, is beyond the scope of this thesis and it will be the object of further research) and the use of at least farm-to-gate and cradle-to-gate as system boundaries.

Level 2 can be seen as the level of intermediate quality. Level 2 starts from Level 1 and adds some extra points. This level is conceived for the Food field that presents a medium quality of used information, according to results shown in this research. This level includes:

- Good definition of the field "Food"
- Consideration of ISO extra points,
- Use of all types of databases to increase the amount of primary data,
- Use cradle-to-gate and cradle-to-consumer approaches as system boundaries (depending on the study focus),
- Consideration of transportation and packaging impacts,
- Analysis of all system impacts,
- Shannon index and equitability calculation (as optional).

Level 3 starts from Level 2 and adds some extra variables. This level is proposed for the Agri-food field because it presents the higher used information quality, according to results shown in this research. Level 3 includes:

- Consideration of ISO extra points,
- Use of all types of databases, increasing the amount of primary data,
- Use of at least cradle-to-consumer and cradle-to-grave as the system boundaries (depending on the focus of the study),
- Consideration of transportation and packaging impacts,
- Consideration of Food Losses in the system - before arriving to the industry and also after leaving the facility - in the consumption and final disposal phases,
- Consideration of credit recycling,
- Shannon index and equitability calculation to measure the amount of information managed and comparing it with the thresholds defined in this thesis.

In summary, it could be said that Field definition and classification by the clustering solution found in this work, along with the roadmap, the good practices manual and the quality levels pointed out could help to gradually improve LCA studies in the Agri-food sector.

6.4 - Limitations

This thesis findings may be somewhat limited by the number of experts who took part in the qualitative analysis. The sample of ten experts from industry and academy should be increased to reach 30 experts from both fields just to benefit from having different experiences and backgrounds. In this line, a comparison between more than two countries and continents also seems necessary to have a broader vision of the sector. Moreover, a horizontal study in the next 5-10 years could help researchers monitor the proposed LCAs improvements and to follow the study's evolution.

Regarding the quantitative study, the analysis of more scientist publications, including other sources, could help researchers set more convenient and reliable Shannon thresholds, as well as to enrich raw data to consolidate the proposed variables and the cluster solution.

Chapter 7

Conclusions and further research

7 - Conclusions and further research

Conclusions

The objective of this thesis was twofold: to perform a critical evaluation about LCA stakeholder's relationships in Brazil and Spain, and to carry out a critical review in order to measure the information quality and quantity enclosed in a sample of LCAs published works in the Agri-food sector.

The obtained results allow stating that LCAs in the Agri-food sector still have room for improvement. Regarding LCA stakeholder's relationships, it could be concluded that the problems and barriers to carry out an LCA study in this sector are not completely new. However, some remarkable differences arise when comparing results from Brazil and Spain. These differences are:

- Lacking of national databases is a bigger problem for Brazilian academics.
- Experts from industry in Spain worry about consumers misunderstanding results, even when positive results are given. This is not the case of Brazilian experts.
- It could be said that LCA experts from academia have more connections with industry in Spain than in Brazil.
- When comparing the results of social network analysis between Brazil and Spain, the indegree and the outdegree are concentrated in Universities in both countries, but in Spain there are more universities that collaborate with industries than in Brazil.

Regarding phase 2 results (quality and quantity of information assessment) it could be concluded that:

- Twenty variables were identified to critically review and evaluate 70 scientific studies.
- There are a few dependences between variables, but they only affect eight out of twenty variables.
- The Shannon index can be used as a valid index to measure the amount of information enclosed in LCA works.
- Thresholds of Shannon diversity index have been proposed to classify LCA information. Equitability has also been calculated to show the variability of inputs used in each study to calculate the impact categories.

- ANOVA results show that LCAs belonging to the Agri-food field enclosed more information than those belonging to the Agro field. In this line, LCAs considering ISO 14040 extra points enclosed more information than those considering only ISO 14040 basic points.
- According to frequencies, distribution and independency among variables, eleven main variables were selected as the most relevant to classify LCA studies.
- Four clusters appeared showing the quality of studies, related to the different categories of the Field variable. Thus, the "Agro" cluster, "Food" cluster and two "Agri-food" clusters were formed, one with a lower quality and the other with the highest quality among clusters.
- A brief roadmap was proposed after the analysis defined practices to be incorporated to improve LCA performance when applied to the Agri-food sector according to the aforementioned clusters. Once the number of clusters that classify LCA applications in the sector were known, as well as its weaknesses and strengths, some practices, methods and tools to improve LCA were defined to be applied in the short, medium and long-term for each cluster qualification.
- Finally, this thesis proposes a good practices manual. This manual suggests a guide to improve LCAs performance in the Agri-food sector, improving current standards achieved by the recent LCA works analyzed.
- Beyond the minimum LCA requirements, three suitable levels of LCA application performance were defined according to the main selected variables.

Future research

Directly related to the aforementioned limitations, is seems necessary to increase the number of LCA experts interviewed in Brazil and Spain, as well as to make contact with experts from different countries to analyse difficulties in different continents. It could be interesting to include the relationship level between LCA's stakeholders in each country and the relationship level between countries to enrich the obtained social network analysis (SNA).

Additionally to increasing the number of reviewed articles, it could be interesting to review LCA publications from other sectors in order to compare the Shannon index values, as well as to set general thresholds values of Shannon diversity index for LCAs in a more reliable way.

The roadmap and the good practices manual outlined here, need to be defined in more detail to really help LCA practitioners improve their results.

The controversial discussion about including Food Losses and packaging recycling in the LCAs is sensible and for this reason it is considered important to trace further articles to evaluate the importance given by authors to these variables in the LCAs impacts from the Agri-food sector. Finally, more accurately modeling consumer behavior in LCAs from the Agri-food sector should be considered in the future. Moreover, end-of-life data is required for modeling waste disposal emissions in more detail. To enable comparison among results, the LCA community needs to develop a common method for modeling consumer behavior, which will be an interesting line for further research.

Chapter 8

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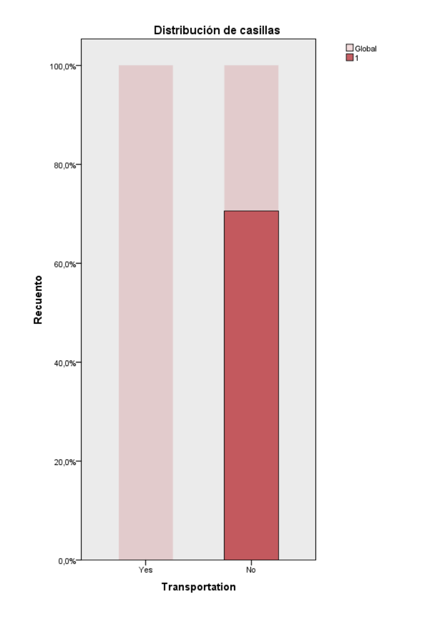
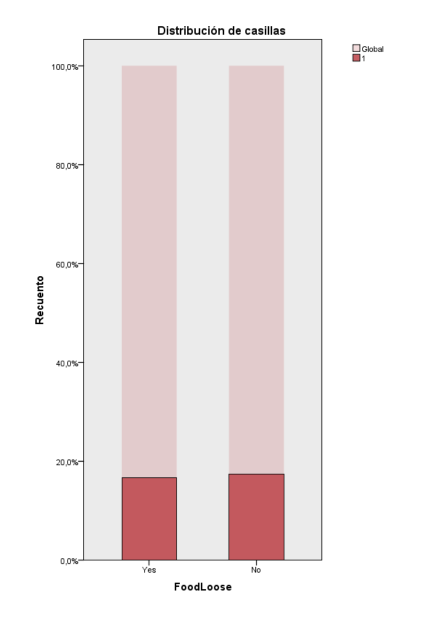
9 - Appendix

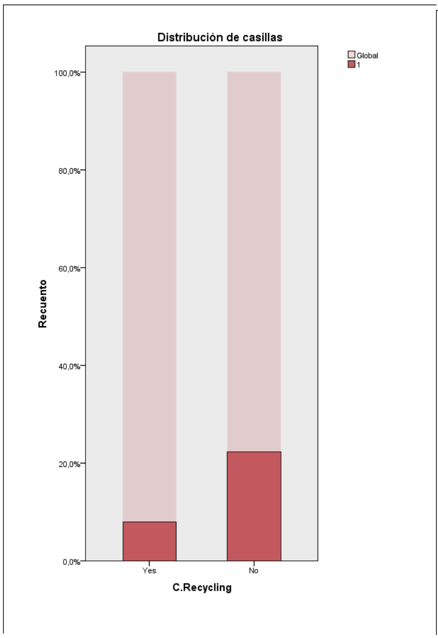
Appendix 1 – List of individuals clustering graphs

Individual graphic of clusters

Cluster 1:



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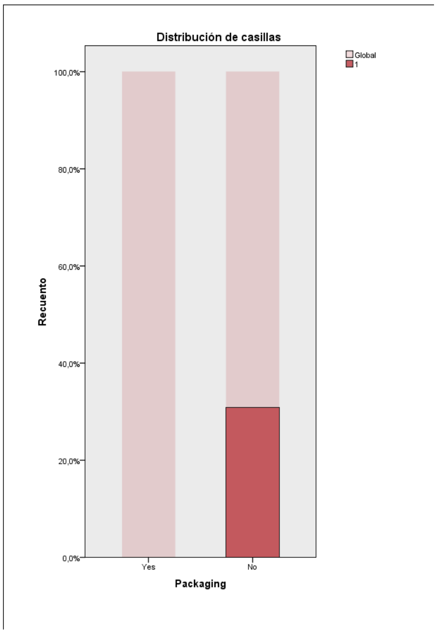
60,0%
40,0%
20,0%
0,0%
Yes
No
C.Recycling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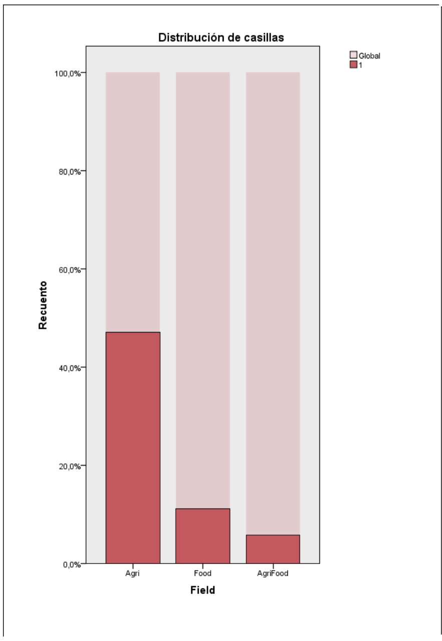
Yes
No
Packaging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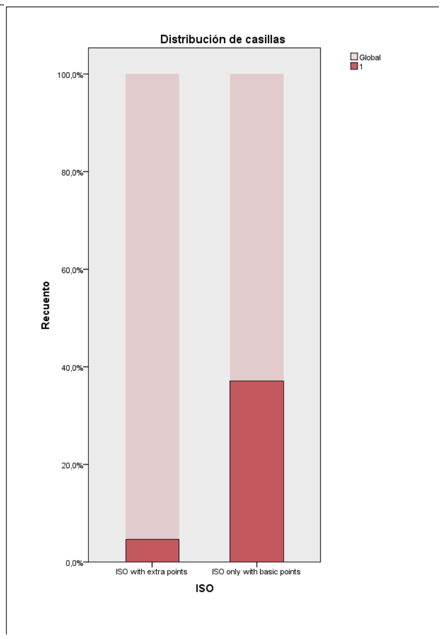
Agri
Food
AgriFood
Field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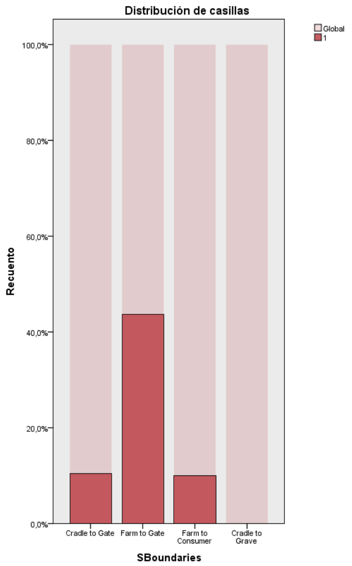
ISO with extra points
ISO only with basic points
ISO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Recuento
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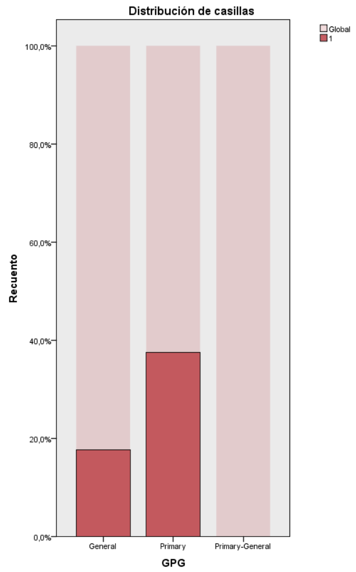
Cradle to Gate
Farm to Gate
Farm to Consumer
Cradle to Grave
SBoundaries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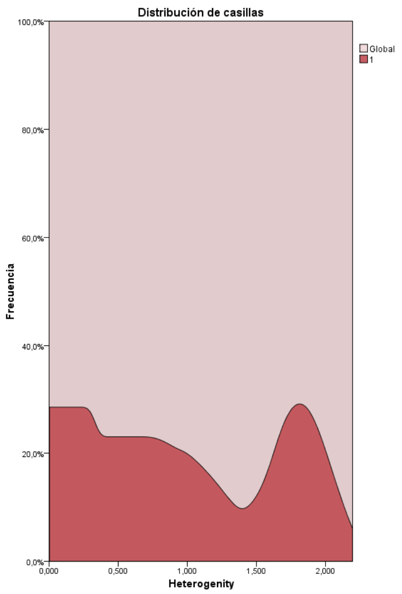
Primary
Primary-General
GPG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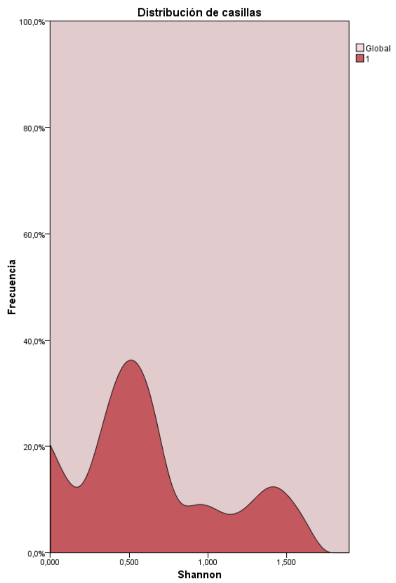
2,000
Heterogenity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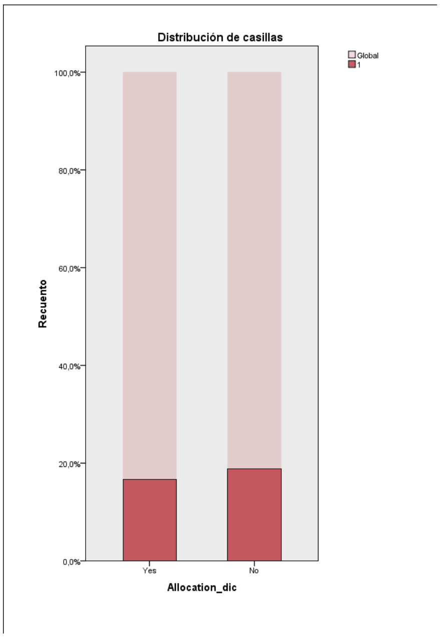
Shannon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Recuento
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No
Allocation_dic

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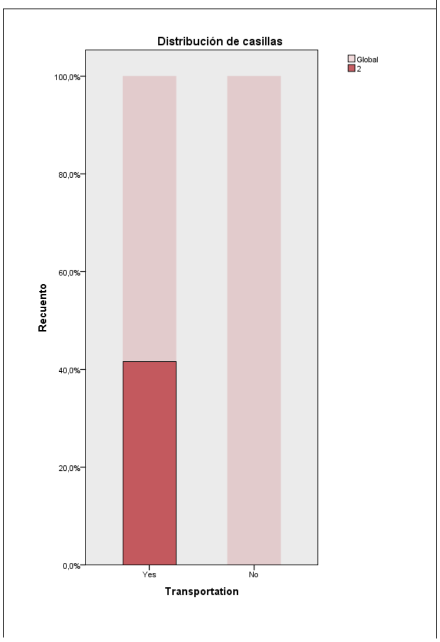
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Recuento
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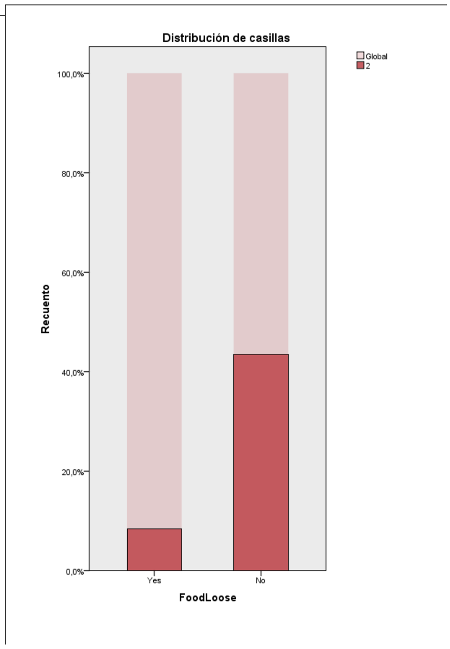
No
Transportation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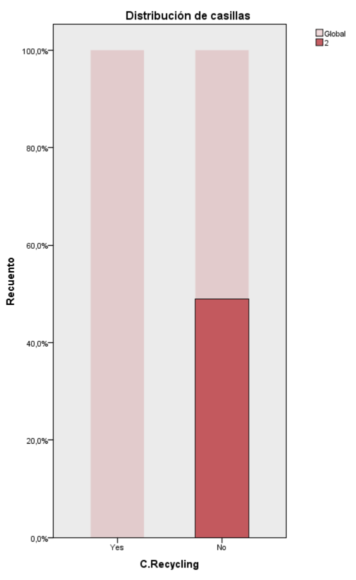
Recuento
Yes
No
FoodLoose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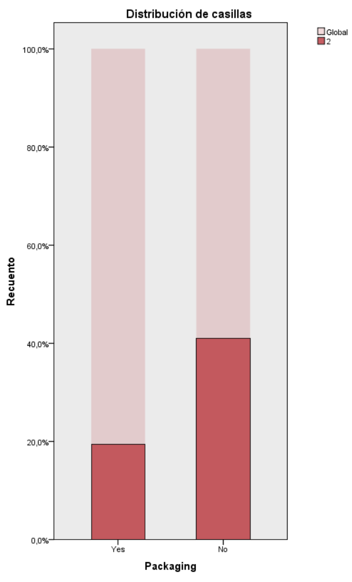
No
C.Recycling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Recuento
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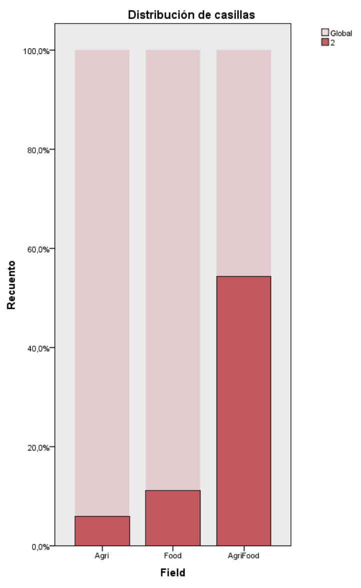
No
Packaging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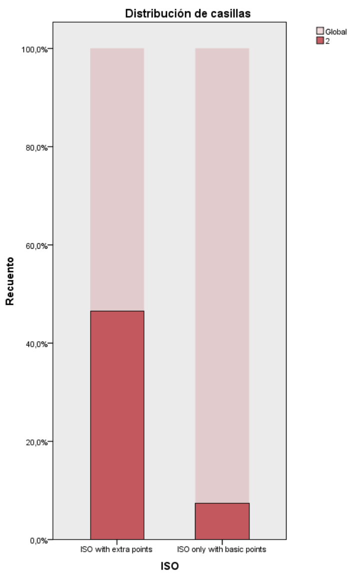
Recuento
Agri
Food
AgriFood
Field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Recuento
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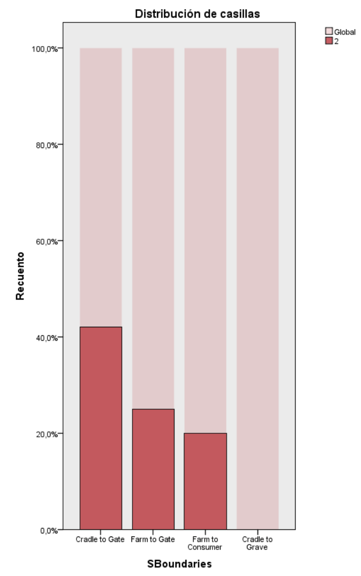
ISO only with basic points
ISO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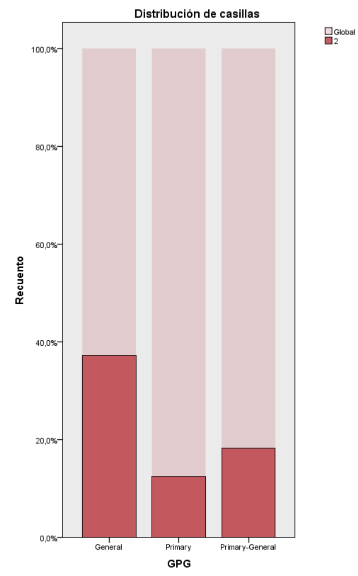
Cradle to Gate
Farm to Gate
Farm to Consumer
Cradle to Grave
SBoundaries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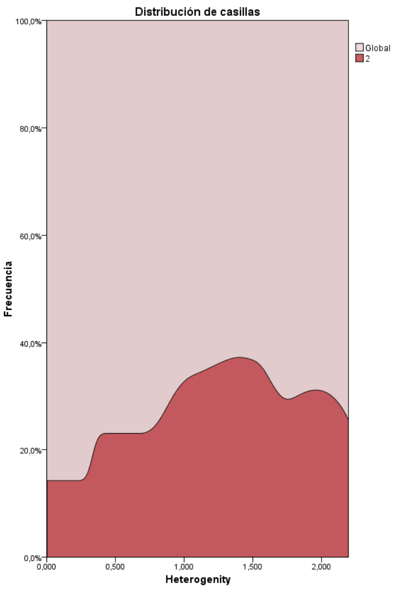
Primary
Primary-General
GPG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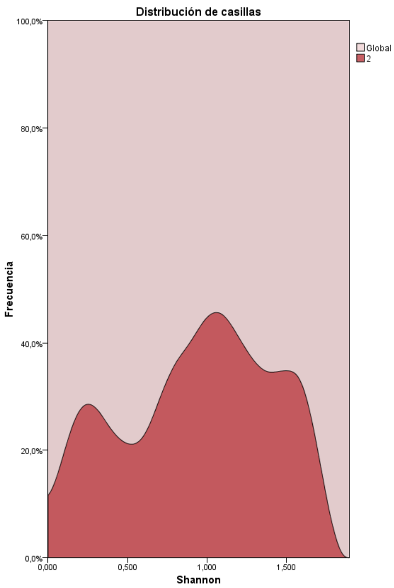
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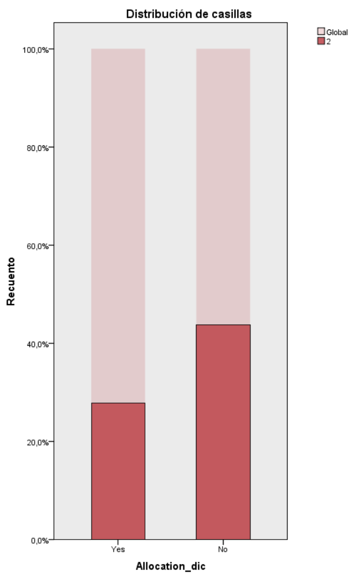
Shannon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No
Allocation_dic

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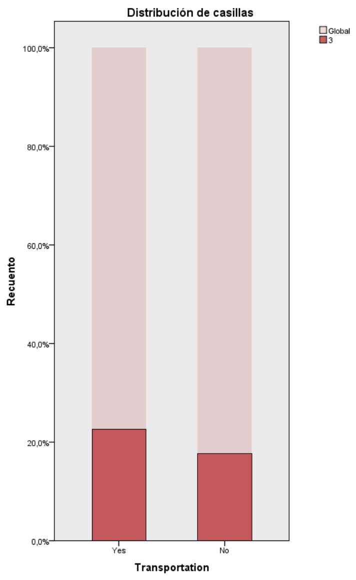
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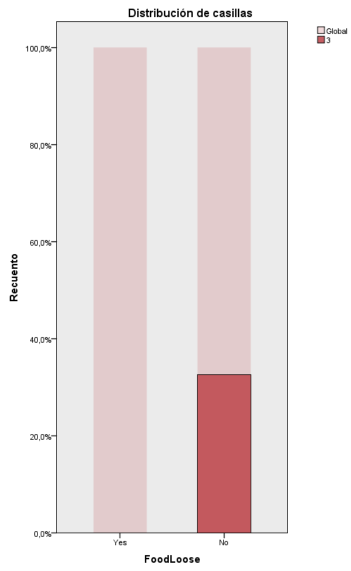
No
Transportation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Recuento
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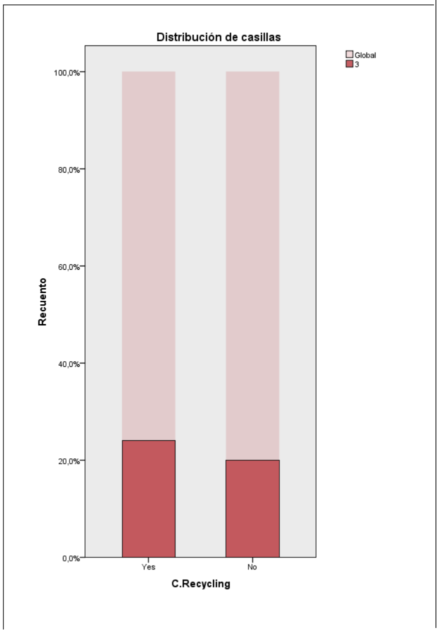
FoodLoose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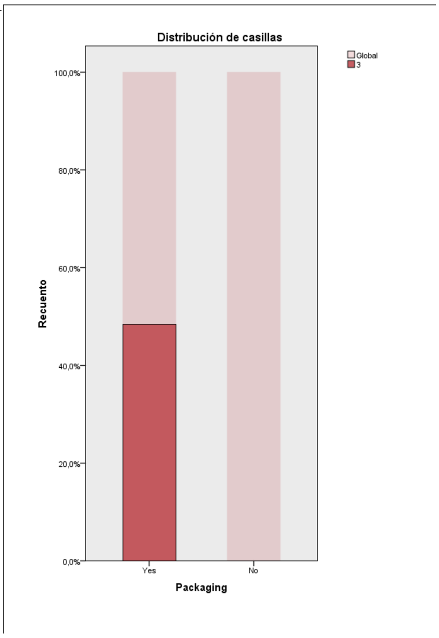
Yes
No
C.Recycling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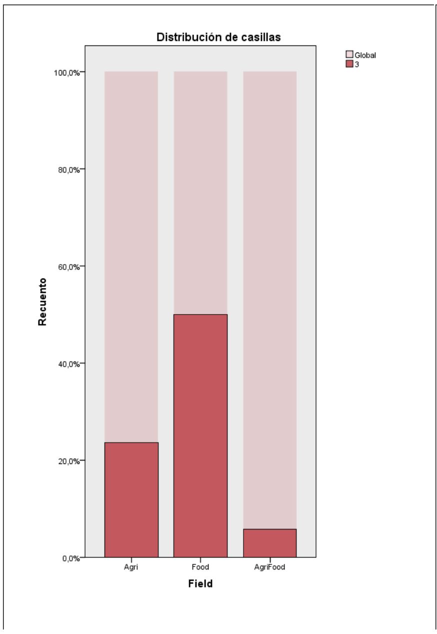
No
Packaging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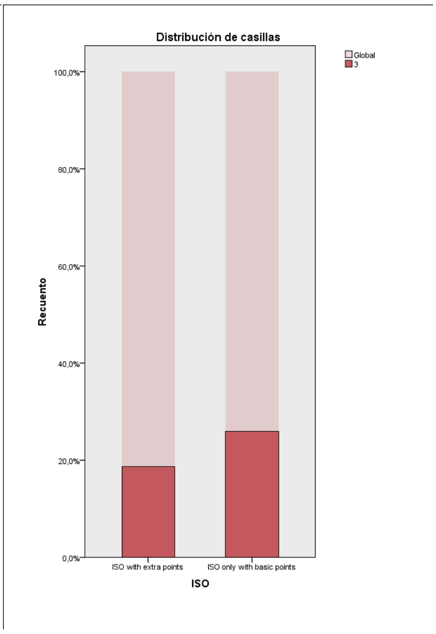
Agri
Food
AgriFood
Field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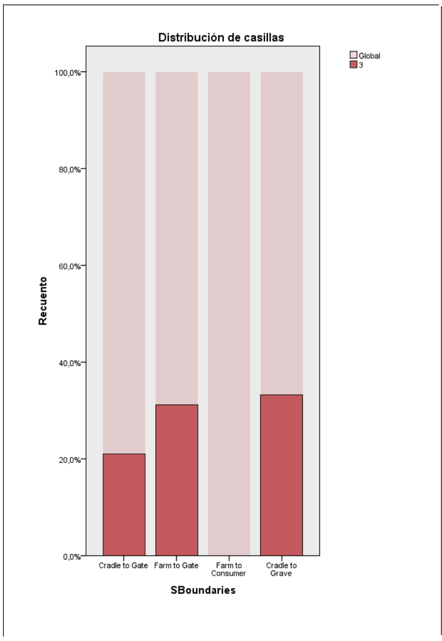
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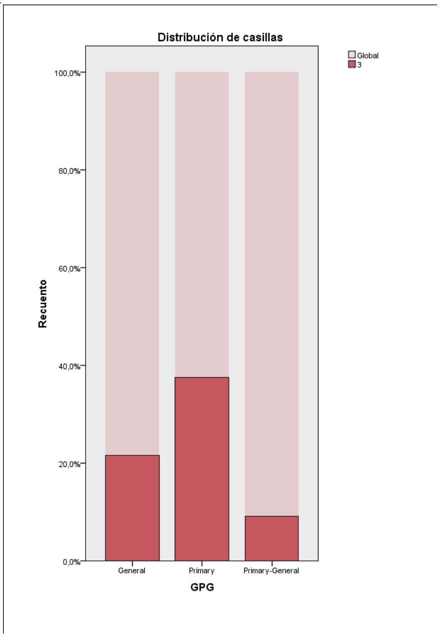
Cradle to Gate
Farm to Gate
Farm to Consumer
Cradle to Grave
SBoundaries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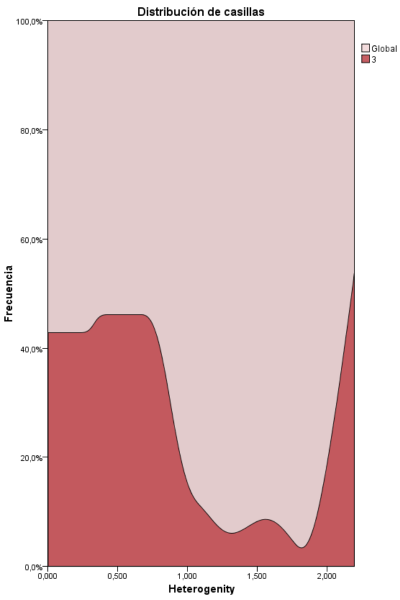
General
Primary
Primary-General
GPG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1,000
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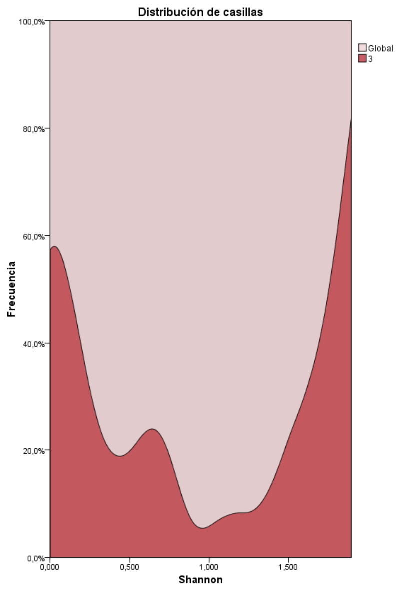
Heterogenity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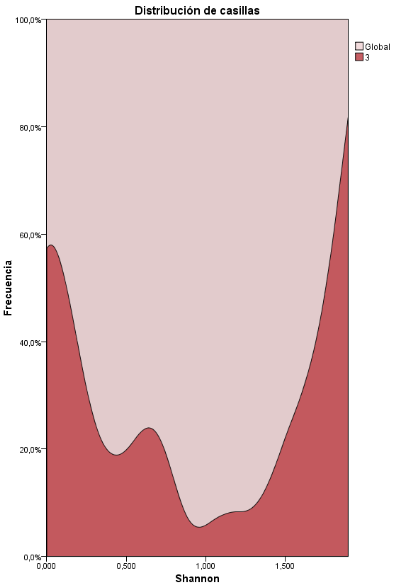
1,000
1,500
Shannon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Frecuencia
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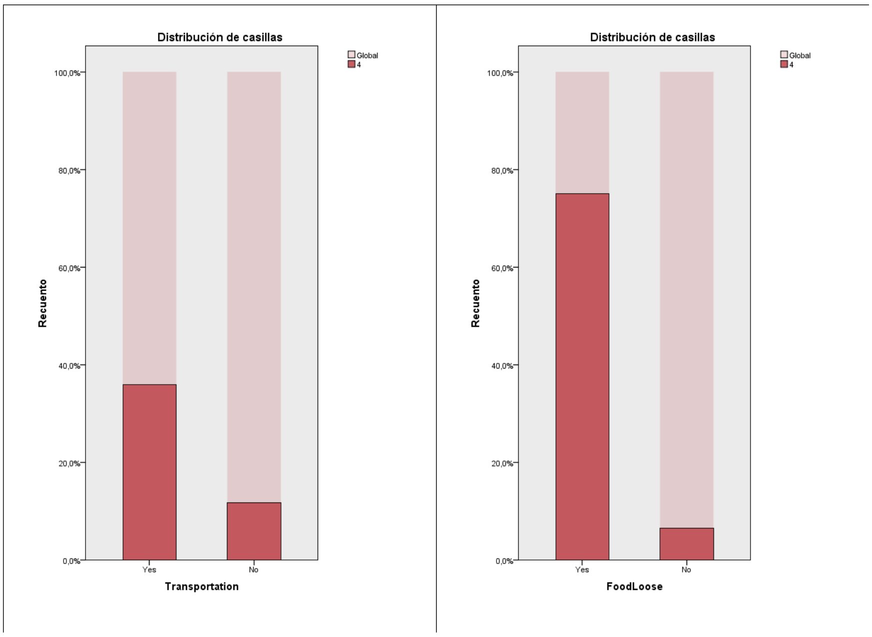
0,500
1,000
1,500
Shannon

Cluster 4: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0,0%
Recuento
Yes
No
Transportation
Distribución de casillas
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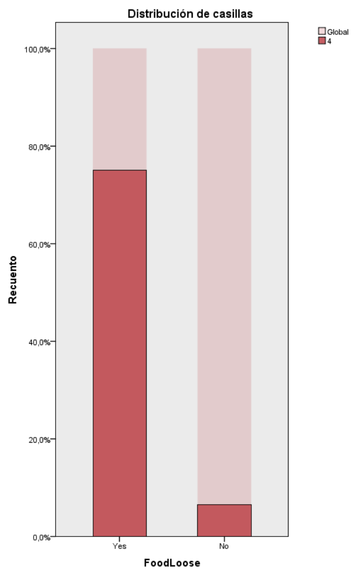
Recuento
Yes
No
FoodLoose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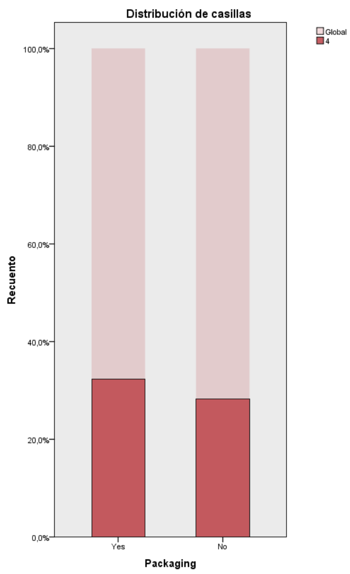
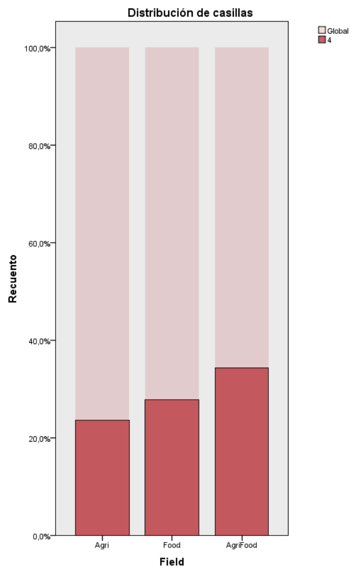
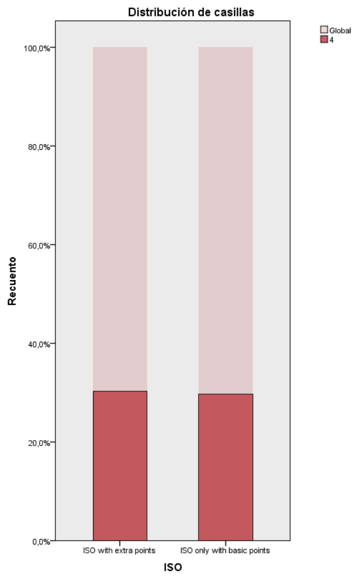
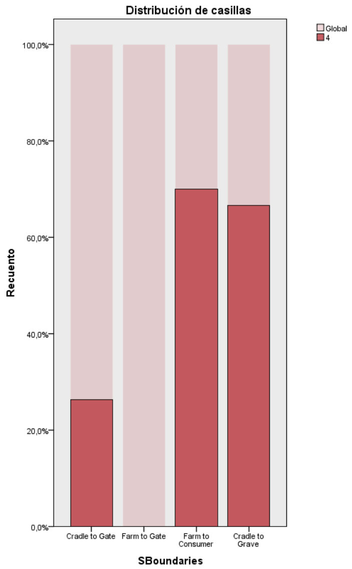
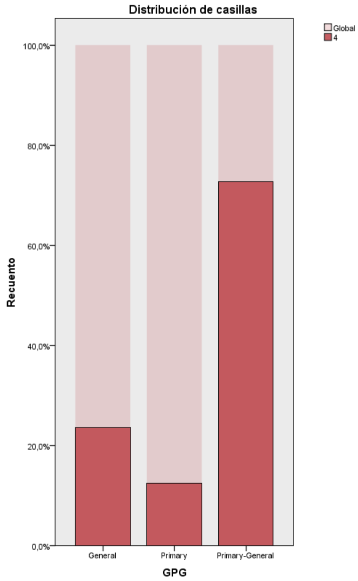
Recuento
Yes
No
FoodLoose

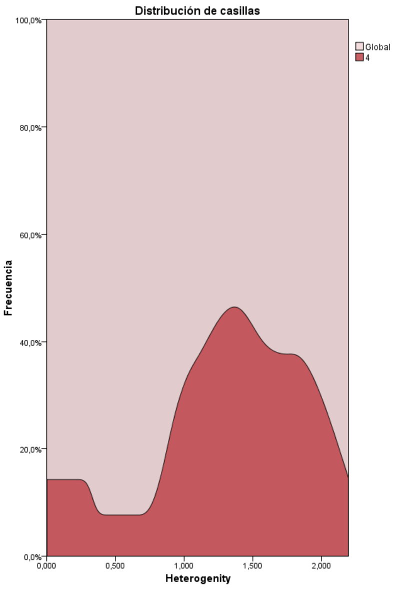

Distribución de casillas
Global
4
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
Recuento
Yes
No
Packaging

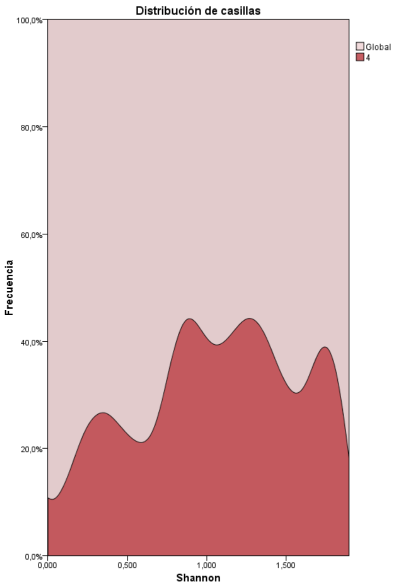

Distribución de casillas
Global
4
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
Recuento
Agri
Food
AgriFood
Field

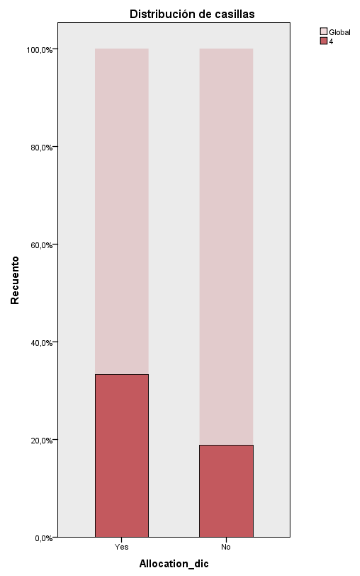

Distribución de casillas
Global
4
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
Recuento
ISO with extra points
ISO only with basic points
ISO


Distribución de casillas
Global
4
Recuento
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
Cradle to Gate
Farm to Gate
Farm to Consumer
Cradle to Grave
SBoundaries


Distribución de casillas
Global
4
Recuento
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
General
Primary
Primary-General
GPG


Distribución de casillas
Global
4
Frecuencia
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
0,000
0,500
1,000
1,500
2,000
Heterogenity


Distribución de casillas
Global
4
Frecuencia
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
0,000
0,500
1,000
1,500
Shannon



Distribución de casillas
Global
4
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
Recuento
Yes
No
Allocation_dic

Appendix 2 – List of experts interviewed

List of experts interviewed in Brazil

Cristiane Leis (USP)
Ana Danke (USP)
Gil Anderi (USP)
Alex Negueira (USP)
Aldo Ometto (USP)
Maria Clara Brandit (UFRJ)
Monique Branco Vierira (UFRJ)
Daniele Bordalo (UFRJ)
Daniele Souza
Sebastião Soares (UFSC)
Leda Coltro (Cetea)
Eloisa Garcia (Cetea)
Anna Lúcia Mourad (Cetea)
Marisa Padua (Cetea)
Josetti Gatti (Cetea)
Fabien Brone (Natura)
Yuki Hamilton Kabe (Brasken)
Sueli Oliveira (Basf)
Guillerme Moraes dos Santos (Basf)
Rafael Vinas (Basf)

List of experts interviewed in Spain

Francesc Tarongi (URV)
Salvador Capuz (UPV)
Daniel Collado (UPV)
Neus Escobar (UPV)
Clara Ramirez Sanz (UPV)
Neus Pellicer (UPV)
Maria José Bastante Ceca (UPV)
Juan Montero (UAB)
Joan Rieradevall (UAB)
Xavier Gabarel (UAB)
Jorge Adobon (Itene)
Mercedes Hortal (Itene)
Juan Adobon (Itene)
Leire Barruetabeña (Gaiker)
Maria Barreiro (Cetaqua)
Xavier Boruel (Cetaqua)
Xavier Fort (Icta)

Jesus Rieves (Inèdit)
Raul Garcia
Nuria Rueda
Gabriela Clemente (UPV)