"Life Cycle Assessment (LCA) as a Decision Support Tool (DST) for the eco-production of olive oil"

TASK 4.3
The implementation of the LCA Methodology

Prepared by

Achilleas Papadopoulos

Andreas Mentzis

Kostas Georgiou

Jorge Molero Cortés

Iñaki Laburu Larrazabal

Marios Avraamides

Despo Fatta

and Giorgos Papadakis

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1 Introduction

This report aims at describing the basic steps of the Life Cycle Assessment (LCA) methodology, for the assessment of the environmental performance of various processes (not only olive oil production). The LCA is a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product

This report will indicate the decisions and assumptions that need to be made, the software that needs to be used / developed and the results that may be obtained.

More specifically, this report comprises the theory, as it was described in Task 2 and the experiences gained during the implementation of LCA for the production of olive oil in Greece, Spain and Cyprus.

Each step of the LCA, as described in the theoretical background is enriched with the methodology that was used for the purposes of this project.

2 LCA Stages

2.1 General

The life of a product starts at the design or development of the product and finishes at end-of-life activities (collection or sorting, reuse, recycling, waste disposal) through the described phases that follow :

- Raw Material Acquisition – all activities necessary to extract raw material and energy inputs from the environment, including the transportation prior to processing.
- Processing and Manufacturing – activities needed to convert the raw material and energy inputs into the desired product. In practice this stage is often composed of a series of sub-stages with intermediate products being formed along the processing chain.
- Distribution and Transportation – shipment of the final product to the end user.
- Use, Reuse, and Maintenance – utilization of the finished product over its service life.
- Recycle – begins after the product has served its initial intended function and is subsequently recycled within the same product system (closed-loop recycle) or enters a new product system (open-loop recycle).
- Waste Management – begins after the product has served its intended function and is returned to the environment as waste.

The main procedure steps for a Life Cycle Assessment are four:

1. Definition of goal and scope of the study.
2. Model preparation of the product life cycle including environmental inflows and outflows. This stage, during which data is collected, is usually referred to as Life Cycle Inventory (LCI).
3. The stage at which environmental relevance of all inflows and outflows are understood, is known as Life Cycle Impact Assessment (LCIA).
4. Finally, study interpretation.

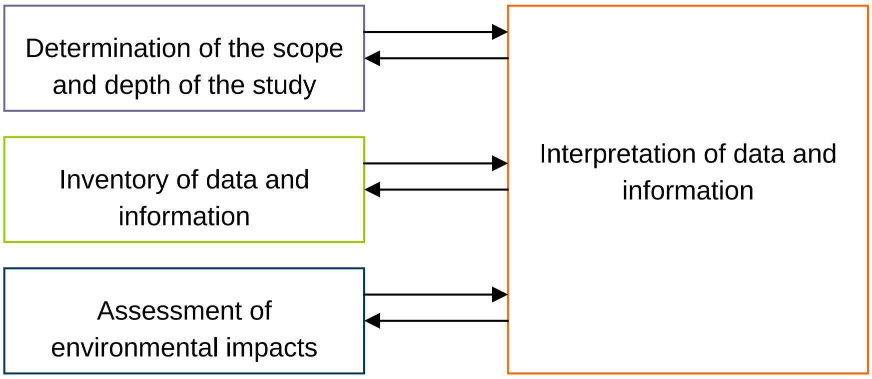

Figure 1: Schematic Illustration of the LCA

Following, the methodology for the development of the aforementioned steps is described, based on the experiences and know-how gained during the implementation of the LCA in the olive oil production.

2.2 Definition of the goal and scope

The definition of the goal and scope of the LCA study is the first and perhaps the most significant step of the methodology. It affects the depth of the study to be carried out, the type of data that need to be collected and the type of results that need to be obtained. Based on this stage the action plan for data collection is developed and the appropriate software that needs to be used is selected.

The most important question associated with goal and scope, are:

- Why is the LCA carried out?
- Who asked for the study – Who is the client?
- Who is going to use the study?
- Does the study include comparisons of several products or processes or assessment of one product or process?
- Which are the actors involved or interested for the results of the study?

Having answered the above mentioned questions, the next step it to define the baseline unit (or functional unit). The results of the study need to refer to a specific functional unit in order to be comparable. The functional unit is the reference to which the inputs and outputs can be related to. This enables comparison of two essential different systems.

The definition of a functional unit could be a difficult task. The unit has to be precise and comparable enough as well easy to be elaborated and connected to the downstream data.

For example, the functional unit for the olive oil production might be:

- 1 lt / tn of olive oil
- 1 tn of olives
- 1 olive tree
- 1 hectare of olive crop

The functional unit used for a project should be determined though the elaboration of the collected data and study. Also, potential restrictions with respect to the depth of the study, the sources and quality of data are determined during the process of the study.

Having determined the functional unit the next step is to determine the product system and its boundaries. The product system is a collection of unit processes, processes, each representing one or several activities, linked to one another by flows of intermediate products and/or waste for treatment. The sum of the unit processes refers to the full “cradle to grave” cycle of the product/process under examination. According to the needs of the study and the assumptions been made it might be necessary to restrict the number of unit processes that will be part of the study. This action refers to the definition of the system boundaries.

The system boundaries determine which unit processes shall be included within the LCA and therefore separate the system from the rest of the world. According to VROM, CML (2001) there are three types of boundaries: [1] the boundary between the product system and the environment, [2] the boundary between processes that are relevant and irrelevant to the product system and [3] the boundary between the product system under consideration and other product systems.

The following boundaries can be considered:

- Boundaries between the technological system and nature. A life cycle usually begins at the extraction point of raw materials and energy carriers from nature. Final stages normally include waste generation and/or heat production.
- Geographical area. Geography plays a crucial role in most LCA studies, e.g. infrastructures, such as electricity production, waste management and transport systems, vary from one region to another. Moreover, ecosystems sensitivity to environmental impacts differs regionally too.
- Time horizon. Boundaries must be set not only in space, but also in time. Basically LCAs are carried out to evaluate present impacts and predict

future scenarios. Limitations to time boundaries are given by technologies involved, pollutants lifespan, etc.

- Boundaries between the current life cycle and related life cycles of other technical systems. Most activities are interrelated, and therefore must be isolated from each other for further study. For example production of capital goods, economic feasibility of new and more environmentally friendly processes can be evaluated in comparison with currently used technology.

The following tables provides the criteria used to determine the system boundaries of the olive oil production, and the processes considered, for the purposes of this study:

Table 1: System Boundary Definition Criteria

Process Category	Included	Exclusion Criteria			
		Low environmental significance	Impossible to obtain representative data	Part of a different system	Not directly relevant to goal of the study
Production, maintenance and replacement of capital equipment		■			
Transportation of capital goods		■			
Production of agricultural inputs (fertilisers, pesticides, herbicides etc)	■				
Transportation of agricultural inputs	■				
Water treatment and supply	■				
Transportation of personnel			■		
Labour activities			■		
Main agricultural activities (application of agricultural inputs, irrigation, soil management, cultivation, pruning, olive collection)	■				
Processing of low quality olives				■	
Main processing activities (storage, purification, grinding, oil extraction, bulk oil storage)	■				
Processing stage waste management activities	■				
Pomace oil extraction				■	
Low quality olive processing				■	
Packaging stage processes					■
Packed oil storage and distribution stages processes					■
Use and end-of-life stages processes					■
Electricity generation	■				

Table 2: Processes considered

Planting the olive trees
Soil Management
Field water supply and irrigation
Fertiliser application
Fertiliser production and transportation
Pruning methods and residue management
Pesticide application
Pesticide production and transportation
Herbicide application
Olive transportation to processing unit
Characteristic olive oil processing
Electricity supply
Water supply
Water treatment
Pre-processing storage of olives
Olive purification
Olive grinding and malaxing
Olive oil extraction
Olive oil storage

During this stage, the assumptions and limitations of the system are determined in terms of:

- pressures and impacts to be assessed

- sources of the data
- technical assumptions

2.3 Model preparation

LCA is a modelling technique where simplifications and assumptions are necessary. The performer tries to describe as realistic as possible a system. Typically, the system is a static simulation model: it consists of unit processes, each representing one or several activities (e.g. production, transportation).

In simple words, model preparation refers to the following:

- Determination of the main processes involved (as defined in the system boundaries)
- Determination of the type of inputs and outputs related to each process. The type of inputs and outputs may include:
    - Energy – fuel
    - Water
    - Products
    - Waste
    - Wastewater
    - Air emissions
    - By-products
- Determination of the specific amount of each input – output in each process unit

During this stage, the data are collected, in order to complete the Life Cycle Inventory (LCI). Reliability of the results from LCA studies strongly depends on the extent to which data quality requirements are met. The following parameters should be taken into account:

- Time-related coverage.
- Geographical coverage.
- Technology coverage.
- Precision, completeness and representativeness of the data.

- Consistency and reproducibility of the methods used throughout the data collection.
- Uncertainty of the information and data gaps.

Threshold points can also be placed in addition to the boundaries, below or above which data collection for inflow or outflow can not be considered, increasing the quality and usefulness of the data.

Several databases and softwares have been developed as LCA modelling tools. These tools have been developed after years of research and analyses, so the best way is to use the appropriate software rather than developing another tool from the beginning, which would be a particularly difficult task, requiring accesses to very detailed data.

The available dedicated LCA software, falls into three categories:

- Generic LCA software: intended for use by researchers, consultants and other LCA specialists.
- Specialized LCA-based software: for specific decision makers, typically intended for use by designers in engineering or construction, the purchasing department, or environmental and waste managers.
- Tailored LCA software systems to be used for clearly defined applications in specific IT environments (as interfaces to business management software). These are usually firm-specific adaptations of generic software or software packages programmed directly for the needs of the firm.

For the purposes of this project, the software SimaPro 6 (System for Integrated environMental Assessment of PROducts), developed by the Dutch PRé Consultants (PRé, 2005), was used.

Similarly, databases included the bulk data required for the LCI. These databases include the main input and output data for several unit processes. Data is separated into two types:

- Foreground data: specific data required to model the specific system. Typically data describing a specific product and production system.
- Background data: information for generic materials, energy, transport and waste management systems. This type of data can be typically found in literature and databases.

Even though much data is available through databases, there are always some processes that are not listed or the available data is not representative of the process required. Strategies are available for the collection of required data

Data collection is usually the most resource-consuming steps of the implementation of the LCA study. For each unit process, within the system boundary defined, quantified data on inputs and outputs must be collected. The categories of data e.g. energy, occupied land, CO_2 emissions etc. that must be targeted during data collection must correlate to the impact categories and characterisation factors included in the impact assessment method to be used. It is highlighted that the data collected for flows can have various units. Furthermore, indicator parameters e.g. biochemical oxygen demand (BOD) may also be used. According to VROM and CML (2001), it is important to distinguish the emissions into the compartment they are released, i.e. air, soil, water and possibly in a more detailed manner, i.e. freshwater, seawater, agricultural soil, industrial soil etc

The use of a transparent format is essential for quality assurance purposes. According to ISO 14049 (2000c), the data collected for each unit process should ideally include: [1] a reference unit, based on one or more incoming or outgoing material or energy flow, [2] a description of what the data includes, i.e. where the process begins and ends and which sub-processes are included, [3] the geographical source of the data and [4] the applied technology.

A distinction should be made between foreground and background processes. Foreground processes are those unit processes for which case-specific primary data must be used, while background processes are those unit processes for which more general information can be used. It is important to remember that the larger the number of the unit processes treated as foreground, the more the detail and accuracy of the study but at the same time the more resource consuming. An example of classification of unit processes included within the system boundary into foreground and background processes for the purposes of this study is indicated in the following table.

Table 3: Preliminary classification of unit processes for data collection

No.	Unit Process	Classification
1	Electricity production	Background
2	Irrigation water supply	Background
3	Irrigation	Foreground

4	Fertiliser production	Background
5	Transportation of fertilisers to farm	Background
6	Fertiliser application	Foreground
7	Pesticide production	Background
8	Transportation of pesticides to farm	Background
9	Pesticide application	Foreground
10	Herbicide production	Background
11	Transportation of herbicides to farm	Background
12	Herbicide application	Foreground
13	Soil management	Foreground
14	Olive tree planting	Foreground
15	Olive Tree cultivation	Foreground
16	Pruning	Foreground
17	Olive collection	Foreground
18	Transportation: Olive farm to production unit	Background
19	Water treatment	Background
20	Water supply	Background
21	Olive purification	Foreground
22	Olive grinding	Foreground
23	Oil extraction	Foreground
24	On-site liquid waste treatment	Foreground
25	Wastewater supply through network	Background
26	Wastewater treatment (public)	Background
27	Pomace processing	Foreground

28	Solid waste treatment	Background
29	Storage of olive oil	Foreground

As mentioned before, the bulk of the data required for an LCA is background information that can be found relatively easy from databases, literature or internet.

Having completed the flow diagram(s), required data sources, types, quality, accuracy, and collection methods, the appropriate data has to be found for the completion of the flow diagram and worksheets with numerical data.

It should be expected that some data may be difficult or impossible to be obtained, and the available data may be difficult to be converted to the functional unit needed. Consequently, this may be the point that system boundaries or data quality goals of the study may have to be refined based on data availability.

An electronic database or spreadsheet can be useful for holding and manipulating the large amounts of data.

Data collection methodologies include:

- Development of questionnaires and distribution to appropriate actors
- Organization of site visits
- Organization of interviews
- Search in the internet and literature

After all necessary data are collected they are imported into the LCA software in order to be processed and the preliminary results on environmental pressures derive (e.g. amount of CO_2 emitted, BOD generated, etc

There are three types of inputs. The first type, inputs from nature, refers to inputs that are extracted from natural resources. It is highlighted that this is just referring to the fact that a resource is used, thus the emissions and other environmental impacts to extract the resource should be included in the process. The second input type, inputs from technosphere (materials /fuel) refers to materials and mass flows respectively supplied by other unit processes, whereas the third type, inputs from technosphere electricity/heat refers to non-mass flows including transport and energy supplied by other unit processes. It is highlighted that the only reason SimaPro separates mass and non-mass flows is to allow easier mass balance checks.

In regards to outputs, for each process, product and by-product outputs as well as waste to be sent to further treatment must be quantified. In addition, data on five elementary output flows must be imported: emissions to air, water and soil as well as final waste flows and non-material emissions such as noise. These elementary data together with inputs from nature will be used in inventory analysis of the product system.

2.4 Life Cycle Impact Assessment

The phase of an LCA called Life Cycle Impact Assessment (LCIA) is the evaluation of the data collected in the inventory, on the basis of potential human health and environmental impacts. More specifically, the purpose of the LCIA is to assess a product system's life cycle inventory (LCI) results in order to better understand their environmental significance (ISO, 2000).

It is a complex procedure, for which the scientific community is often in disagreement both on the methodology to be used (Rebitzer et al., 2001) and also on the interpretation of the results obtained using different approaches (Finnveden, 2000). This complexity lies in the cause-effect chains, linking inventory emissions and resource depletion to the consequences. As shown in the following figure, the impact chain describes the environmental mechanism from "exchanges" to "endpoints". An "endpoint" is something that we want to protect (a value item) such as trees, crops, rivers and human health. A "midpoint" in the other hand, refers to all elements in an environmental mechanism of an impact category that fall between environmental exchanges and endpoints (Udo de Haes et al., 2002a). An example of an exchange is the emission of CFC gases, which causes depletion of the ozone layer in the stratosphere (mid-point), which results in increased levels of radiation (mid-point) that eventually cause a certain number of people to die from skin cancer (end-point) depending on exposure and sensitivity on receiving environment (dark versus light skin colour, amount of sun block etc.).

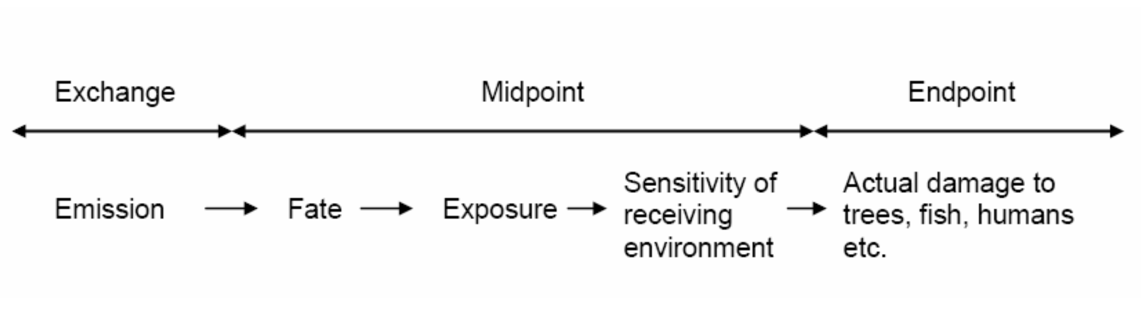

Figure 2: The impact chain for an emission of a given substance (Hauschild, 2003)

Due to the intricacy of evaluating the cause-effect chain of each environmental problem, many LCIA methods have been published and used by LCA practitioners. According to Thrane and Schmidt (2004), LCA practitioners often choose a method for impact assessment, which is developed in the country where the LCA is carried out. However, when none of the available methods was developed locally, as is the case in this study, it can be an advantage to use several methods for verification purposes since more impact categories will be covered, as different methods tend to include different impact categories.

In regards to the approach followed by each method, the majority of methods ISO 14042 (2000) defines a standard methodology for the assessment of impacts comprises, as shown in the following Figure.

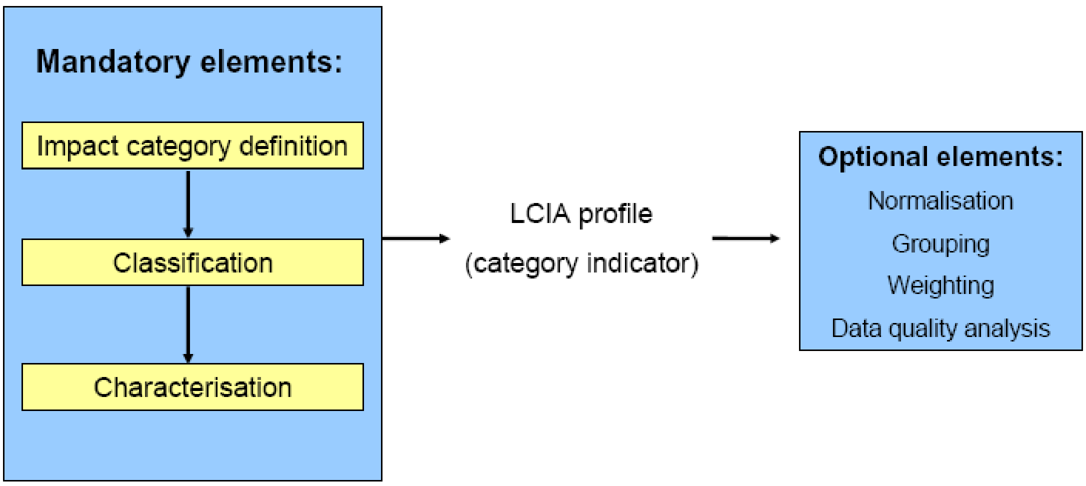

Figure 3: Life Cycle Impact Assessment according to ISO 14042

According to this methodology, LCIA comprises of:

1. Selection of the impact categories of interest, the indicators for each impact category and, although often implicitly considered by practitioners, the underlying models (a procedure also considered in the initial goal and scope phase of an LCA). Climate change, stratospheric ozone depletion, photooxidant formation (smog), eutrophication, acidification, water use, noise, etc. are included into the impact categories

2. Assignment of the inventory data to the chosen impact categories (classification). Calculation of impact category indicators using characterisation factors
3. Calculation of category indicator results relative to reference values(s) (normalisation, optional).
4. Grouping and/or weighting the results (optional, weighting not being allowed when following ISO14042 in comparative assertions disclosed to the public)
5. Data quality analysis (mandatory in comparative assertions disclosed to the public, according to ISO 14042, but receiving little attention in current practice).

According to ISO 14042 (2000) steps [4] and [5] are optional in the impact assessment methodology.

SimaPro 6 software includes a number of standard methods as listed in the following table. These methods have been primarily prepared for the assessment of a product or service and through a number of alterations but with minimum changes to the principal models they have been introduced to the software (PRé Consultants, 2004). Additional changes to the methods are made throughout the years according to new findings on the environment, processes etc.

Table 4: Standard impact assessment methods available in SimaPro 6

Methodology	Developer
CML 1992	Centre for Environmental Studies, University of Leiden part of Dutch Guide to LCA
Eco-indicator 95	PRé Consultants part of Integrated Product Policy of the Dutch Ministry of Housing, Spatial Planning and the Environment
Ecopoints 97	Swiss Ministry of the Environment part of Ecoipoint System
Eco-indicator 99	PRé Consultants part of Integrated Product Policy of the Dutch Ministry of Housing, Spatial Planning and the Environment
CML 2 baseline 2000	Centre for Environmental Studies, University of Leiden part of Dutch Guide to LCA
EPS 2000	Centre for Environmental Assessment of Products and Material Systems. Chalmers University of Technology, Technical Environmental Planning for Environmental Priority Strategies in product design
EDIP	Danish UMIP for Environmental Design of Industrial Products
IPCC 2001 GWP	Intergovernmental Panel on Climate Change (IPCC)
Cumulative	PRé Consultants

Energy Demand

Following the LCAI, comes the interpretation phase. The aim of the interpretation phase is to reach conclusions and recommendations in accordance with the defined goal and scope of the study. Results from the LCI and LCIA are combined together and reported in order to give a complete and unbiased account of the study. The interpretation is to be made iteratively with the other phases.

The life cycle interpretation of an LCA or an LCI comprises three main elements:

- Identification of the significant issues based on the results of the LCI and LCIA phases of a LCA.
- Evaluation of results, taking into consideration completeness, sensitivity and consistency checks.
- Conclusions and recommendations.

2.5 Type and format of the reports

Reporting is a crucial issue in LCA. A technically excellent LCA without a transparent and unambiguous report will be of limited value. Thus the basic requirement of the report is transparency. The reader of the report should be able to understand what has been analysed, how allocations issues were handled, and what data was used. A non-exhaustive list of what must be included in the final report of this study is provided in the following table.

Table 5: Format of final report

Chapter	Subchapters	Contents
Front Page	-	- Title of project - Course number - Date - Group number - Authors and affiliations
Executive Summary	-	- A non-technical summary statement designed to provide a quick overview of the full-length report
1. Introduction	-	- A statement that the study has been conducted according to the requirements of International Standard ISO 14040 (1997) - Background of the problem
2. Goal and Scope of the Study	2.1 Goal of the Study	- Reasons for carrying out the study - Intended application - Practitioner, intended audience and interested parties
	2.2 Scope of the study	- Description of the Product System - Definition of system boundaries - Description of the functions of the product system - Definition of the functional unit and reference flows - Allocation procedures - Types of impacts considered in the model and impact assessment method used - Data collection plan - Limitations and assumptions

3. Life Cycle Inventory Analysis	3.1 Process Flowchart	- Flowchart including processes that are included in the modelled product system - Processes related to the system that have been excluded
	3.2 Data	- Documentation of the data, assumptions, allocation procedures, and data gaps related to each process of the product system - Description of the data used - Documentation of foreground data obtained for this study with source, assumptions, and calculations - Documentation of data from databases in SimaPro with complete reference to the database and the process name - Documentation of data from other LCA sources with complete reference.
4. Life Cycle Impact Assessment	4.1 Impact categories	- Description of the impact categories assessed and common sources of such impacts
	4.2 Classification	- Documentation of classification of resource consumption and emissions to impact categories
	4.3 Characterisation	- Documentation of characterisation factors used
	4.4 Normalisation and Weighting (if applied)	- Documentation of normalisation and weighting method used
	4.5 Results	- Presentation and analysis of results - Identify significant impacts and significant life cycle stages - Explain the cause (source and emission) of main impacts - Explain important differences between alternatives.
5. Life Cycle Interpretation	5.1 Data Quality Assessment	- Data quality assessment - Consistency check - Contribution analysis - Anomality assessment

	- Notes on validity of choices in goal and scope definition - Notes on appropriateness of impact assessment methods - Notes on major uncertainties in the data and model
Conclusions and Recommendations	- Provide conclusions in regards to the stages of the olive oil production cycle that have significant impact to the environment - Based on the results of the study provide guidelines on the selection of particular processes to reduce the environmental impacts
References	- Complete list of references, ordered in alphabetical order

3 Project Conclusions and future research needs

3.1 Application of LCA

The LCA is a particularly useful in assessing the environmental impact of a series of processes or activities employed for the production of specific products. It provides detailed quantified information on the specific emissions and consequent environmental impacts related with each stage in a production process, allowing its user to identify the most critical stages, in terms of environmental damage. Therefore, it allows the adoption of stage specific measures to address the most significant environmental impacts related with the production of the product under examination.

Also, the LCA allows the comparison of different processes for the production of the same good in order to select and promote the one that generates less environmental burden.

Moreover, the LCA, combined with other well elaborated tools, such as Cost Benefit Analysis, may provide an integrated view, in terms of both environmental and financial aspects, in order for the decision makers to reach the most appropriate decision, based on the specific characteristic of the area of concern.

3.2 Results and Interpretation of LCA

Industrial Agriculture generates main environmental impact from those processes associated from inputs coming from Agro-industrial Inputs: production of fertilizers, pesticides as herbicides as well as on field use and emissions from technosphere.

Main environmental impact in agriculture come from intensification of production and thus, alternative agricultural systems are needed.

3.3 Proposals

Proposals range from short to long term, from applying actual partial solutions to a redesign of the system: from global economies to local ones, from conventional-intensive in technology and resources agriculture to an organic-intensive in knowledge one.

The eco-production of olive oil by farmers and oil mills must be assured by an eco-consumption of olive oil, where consumers are a key role of this change.

3.4 Overall conclusions and further research needs.

Drastic changes are needed to achieve a real sustainable society. Oil must be consumed in a local scale and must get a fair price for its production, avoid intermediaries between producer and consumers. This independence from the market and global scale decision will allow farmer to achieve real organic agriculture, based in agronomical and not economical criteria.

Although, consequences of a broad implementation of this principles at a local/regional levels will:

- Optimize the use of agricultural land and increasing space for natural areas
- Maximize biodiversity in both agricultural and natural lands
- Dignify agricultural tasks
- Sustain local economies
- Others

Further studies should be made comparing ecological vs. conventional agricultural production of olive oil involving complex factors as pomace processing, Biofuel production, and others.

Thus, participatory local research in farming and agro-industry is needed to implement this set of recommendations. Energy, mass (specially water) and information balances, using several environmental methodologies (LCA, Ecological Footprint and others) as well as on-farm agricultural research are key point to obtain sustainability in its broader sense.

Scientific knowledge in natural and social sciences in last decades have shown relations among different actors (humans and not humans) involved in agricultural production. It is a shame that even nowadays, a technocratic approach still been used when trying to solve environmental problems that in most cases, an they can only be solved by a social involvement.

Future sustainable management of resources will be knowledge intensive and will minimize technology use, lowering dependencies of farmers from industry.

4 General conclusions

The LCA is a useful decision making tool for the determination of the optimum processes, in terms of environmental performance, for (the list is non-exhaustive):

- the production of various products
- the management of waste / wastewater
- the transportation of goods

However, the results of the LCA highly depend on the assumptions made, the system boundaries and the functional unit. In the past, different LCA studies examining the same issues came up with different results. For example LCA studies carried out for the management of waste oils indicated in one case that waste oil incineration is better than regeneration and in the other case the exact opposite.

This does not mean that the results are biased but that the initial assumptions made and the system boundaries are in favour of the one or the other solution.

Hence, the LCA tool should be seen as a supporting tool and not as the only source of data and conclusions.

It is expected that the implementation of LCA will further grow in the near future especially in fields where it has nit been applied a great deal, such as waste management. It is up to the users of the tool to utilize its potential in an objective manner and not try to adopt the tool to their priorities or benefits.

Finally, when carrying out LCA, it is necessary to consider:

- It is very important to take into account infrastructure as it is very important for future comparisons between alternatives.
- The application of LCA is useful in “Ecological Economics”. Chrematistics vs management of resources
- LCA analysis allows us to perform more global than regional and local environmental impacts studies, as most pollutants have been introducing regarding to atmosphere compartment. Regional and especially local environmental impacts are much site dependent because most environmental impacts rely on soil and biodiversity. For analysis of local areas, other environmental methodologies should complete this approach.
- It has been difficult to obtain information of olive tree cultivation in Ribera Baja as well as impossibility to perform exact calculations.
- LCA is a complex but valuable tool for environmental assessment