POSTER SESSION E
Mediterranean diet case studies

Including more technology in the production of a quality wine: the importance of functional unit

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ABSTRACT
Differently from what it could be thought, wine production really is a complex activity in which the technology plays the same important role of the grape cultivation and of the winemaker skills. Even if the raw materials are just grapes, yeast and some chemicals, the alternative processes are so various to give wines with very different quality levels. Despite the great variety of wines most of the LCA studies of wine and, above all, those ones with comparative aims consider as functional unit a specific amount of product in litres or kilograms, without any reference to the main characteristics of products. In this paper, the production system of a red wine will be analized through life cycle assessment and compared with a quality wine. The results of this study show how the environmental performance of wine production changes if more technologies are used in order to obtain a high quality level wine and how much the results could change if a different functional unit is used.

Keywords: Wine, technology assessment, quality products, functional unit

1. Introduction

The application of Life Cycle Assessment to the case of wine production is not a simple task because of different problems. Apart those related to the wine typical nature of agro-industrial product which, consequently, involves both an agricultural and an industrial phase with all the difficulties linked to the assessment of the agricultural environmental burdens, the main problems of the LCA application to wine production deal with the production process itself.

Differently from what it could be thought, wine production really is a complex activity in which the technology plays the same important role of the winemaker skills and of the wood storing. Even if the raw materials are just grapes, yeast, and some chemicals, the alternative processes are so various to let the traceability of wine a very difficult work. Although the basic steps used in wine making are very similar for small producers of the highest quality wines, large producers of inexpensive wines and home wine makers, the size and sophistication of the equipment enormously vary. In a modern winery, the grape route to become wine goes through different thermal, clarification, filtration, stabilizing and ageing processes, whose involvement or not leads to very different qualities of wine. Therefore, it is quite difficult to state a "formula" or a raw material mix for wine production, on which to built up an inventory table of the relative inputs and outputs, since it remarkably changes according to the grape variety and to wine quality and price (Notarnicola *et al.*, 2003). Moreover, the use of technology is made to increase the quality of wine and to avoid defects; this could lead to a higher consumption of energy, materials and chemicals which, in terms of LCA, could mean a higher environmental impact.

Despite the great variety of wines most of the LCA studies of wine and, above all, those ones with comparative aims consider the final products as having the same characteristics. As a consequence, the functional unit used is a specific amount of product in litres or kilo-

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grams, without any reference to the main characteristics of products. Also the Product Category Rules (PCR) for preparing an environmental product declaration (EPD) for packaged sparkling red, white and rosé wines suggest as functional unit 1 litre of wine (SW.E.M.C., 2006). In a recent study Petti *et al.* have carried out a state of the art in LCA of wine industry whose aim is, starting from the analysis of the recent national and international literature on wine LCA, the investigation of the main methodological choices made in the wine LCA studies (Petti *et al.*, 2010). In this study we have the confirmation that functional unit is one of the main problems to face with when a LCA of wine is carried out; in fact, most of the analysed studies consider a standard amount of wine (usually 750 mL, which is the content of a commercial bottle) as functional unit; the authors underline the need for an accurate definition of functional unit, above all when different types of wine are compared, because the functional performance of the products could not be easily related to a certain amount of wine. In a previous study (Notarnicola *et al.*, 2003) the environmental profile of four wines was build up. Even though in this study there was no comparative aim, since white and red wine or high quality and average quality wine don't represent "perfect substitutes" but completely different wines, the reasons of the differences in each wine environmental profile were examined. To make this, the functional unit chosen was one 0.75 L bottle of wine with the specification of the selling price as indicator of a different quality of wine.

In this paper, the production system of a red wine will be analysed through life cycle assessment and compared with a quality wine. The aim of this study is to investigate how the environmental performance of wine production changes if more technologies are used in order to obtain a high quality level wine and how much the results could change if a different functional unit is used.

2. Life cycle assessment of wine production

Goal of the study is to build up the environmental profile of two wines, in order to identify the hot spot of the two systems and compare them. The first one is a red wine with an alcoholic degree of 10% in vol. The production system of this red wine has been analysed in a previous study (Notarnicola *et al.*, 2003). The other wine is obtained with the same production process of the red wine previously analysed but with the inclusion of other phases and, therefore of more technology; this phases are related to the reverse osmosis treatments of must to enrich the alcoholic content of wine. The final wine is a quality wine with an alcoholic degree of 11% in vol. The technologic treatment of must by reverse osmosis has been analysed in previous studies (Notarnicola *et al.*, 2007; Notarnicola *et al.*, 2008).

The functional unit chosen is 1 hL of bottled wine in 0.75 L bottles; therefore 133.33 bottles with a 0.75 L capacity are needed per functional unit.

In the following, we report the main assumptions and features of the study; more detailed information about processes and inventories could be found in the cited studies.

The analysis is from "cradle-to-gate", covering all the life cycle phases, starting from the production of the input used in the agricultural phase (fertilisers and pesticides) until the production of the bottled wine, including production of the barrique, glass bottle, cork tap, aluminium capsule and paper label.

The foreground data have been directly supplied by the company analysed, which makes use exclusively of grapes produced in its estate vineyards. The background data are taken from the LCA databases. The emissions of N_2O, NH_3, NO_3-, due to the use of nitrogen fertilisers have been modelled respectively following Houghton (Houghton, 1997), ECETOC (ECETOC, 1994) and Brentrup (Brentrup et al., 2000) methodologies. The emissions of pesticides (in particular, dicobutrazol, folpet, propiconazole, metalaxil, phosalone, oxyfluorfen) during their use have been assessed following the model developed by Hauschild (Hauschild, 2000). The allocation problems, in particular the one relative to wine and pressed wine, have been solved on the basis of mass.

The co-products leaving the systems, rasps, lees and marc have been considered as solid waste for which there is no disposal treatment, since they become free of charge raw materials for other productions, respectively compost for rasps and tartaric acid for marc. The emissions of carbon dioxide occurring during the fermentation process have not been taken into account. The inventory results expressed in physical units have been assessed by the CML 2000 assessment method (Guinèe et al., 2002); the assessment method has been stopped to the characterisation, without going through the normalization and weighting steps.

2.1. Inventory analysis

The quantitative inputs of the two systems are shown in Table 1. As it can be noted, the quality wine has higher values per functional unit than the simple red wine for most of the inputs. This is due to the fact that the technology used to enrich the must, the reverse osmosis, is a subtractive method; indeed, starting from 1000 L of must, 909 L of enriched must can be obtained, while the remaining 91 L get out the machine as permeate. The result is the need of more grapes to produce the same amount of wine, with a higher impact in the agricultural phase, and the relative higher consumption of electric energy and auxiliaries to treat more grapes in the winery. Besides, the insertion of the reverse osmosis operation adds up further electric energy consumption, which is increased of about 25% in the industrial phase.

Table 1: Inputs of the two systems per functional unit

Input	Red wine (g)	Red wine + osmosis (g)
Agricultural phase		
Diesel	956.00	1045.35
Lube oil	28.00	30.62
Fertilisers		
N	1098.67	1201.35
P_2O_5	257.33	281.38
K_2O	642.67	702.73
Pesticides		0.00
Copper oxicloride	117.33	128.30
Dicobutrazol	13.33	14.58
Folpet	45.33	49.57
Wet sulphur	70.67	77.27
Sulphur	324.00	354.28
Propiconazole	6.67	7.29
Metalaxil	140.00	153.08
Phosalone	46.67	51.03
Oxyfluorfen	20.00	21.87
Industrial phase		
Grapes (kg)	142.67	156.00
Electric energy (kWh)	3.60	4.48
LPG (m^3)	0.00002	0.00002
Diesel	506.67	506.67
Water (L)	150.67	153.30
SO_2	16.00	17.60
N_2	62.67	62.67
Others		
Barrique	8000.00	8000.00
Glass for the bottle (kg)	66.67	66.67
Cork	453.33	453.33
Aluminium capsula	142.67	142.67
Paper label	165.33	165.33

2.2. Impact assessment

In the Tables 2 and 3 the results coming from the characterization phase of the two systems are shown per phase. In Figure 1, instead, the total characterization indicators of the two systems are compared. As expected, following the considerations made in the inventory phase, it can be easily found out that the quality wine is more burdening in all the impact categories with percentage from 3% to 9%. By including more technology in order to produce a quality wine gives the result of a worst environmental performance if the comparison is made on the basis of volume or mass. But, if we consider the function of the systems in a different way maybe a different functional unit is adoptable.

Table 2: Characterization indicators of red wine system per phases (per functional unit)

Impact categories	Units	agricolture	manufacturing	packaging	Transports	Total
ADP	kg Sb eq	0.050	0.067	0.0283	0.013	0.158
GWP	kg CO2 eq	10.163	10.610	35.894	2.061	58.728
ODP	kg CFC-11 eq	1.19E-06	2.99E-06	1.48E-06	1.74E-06	7.39E-06
HTTP	kg 1.4-DB eq	1.252	1.654	4.512	0.395	7.813
FAETP	kg 1.4-DB eq	48.780	0.224	0.170	0.031	49.206
MAETP	kg 1.4-DB eq	1548.8	808.9	1252.0	69.5	3679.3
TETP	kg 1.4-DB eq	1.024	0.025	0.032	0.0005	1.082
POCP	kg C2H2	0.0045	0.0295	0.0098	0.0003	0.0441
AP	kg SO2 eq	0.211	0.074	0.236	0.022	0.542
NP	kg PO4--- eq	0.1114	0.0001	0.0009	0.0047	0.1171

Table 3: Characterization indicators of red wine system + osmosis per phases (per functional unit)

Impact categories	Units	agricolture	manufacturing	packaging	Transports	Total
ADP	kg Sb eq	0.0545	0.0720	0.0283	0.0131	0.1679
GWP	kg CO2 eq	11.179	11.301	35.894	2.106	60.480
ODP	kg CFC-11 eq	1.31E-06	3.34E-06	1.48E-06	1.78E-06	7.90E-06
HTTP	kg 1.4-DB eq	1.378	1.902	4.512	0.404	8.196
FAETP	kg 1.4-DB eq	53.659	0.262	0.170	0.031	54.122
MAETP	kg 1.4-DB eq	1703.3	959.3	1252.0	71.1	3985.8
TETP	kg 1.4-DB eq	1.126	0.030	0.032	0.0005	1.189
POCP	kg C2H2	0.0050	0.0323	0.0098	0.0003	0.0474
AP	kg SO2 eq	0.232	0.080	0.236	0.022	0.570
NP	kg PO4--- eq	0.1228	0.0001	0.0009	0.0048	0.1286

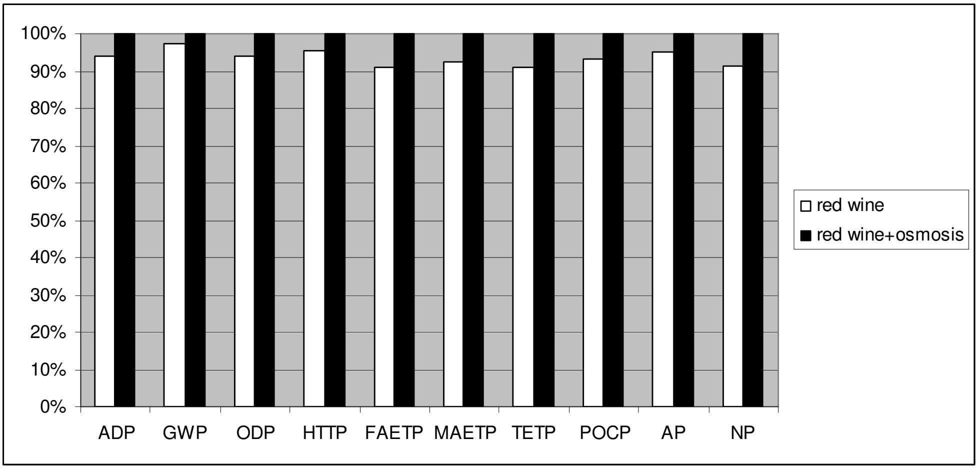

Figure 1: Characterization of the two systems

The function of the wine system is to produce a beverage with a certain alcoholic degree; the more this content is high, the more the value and quality of wine are; moreover, the reverse osmosis is a technology used just to increase the alcoholic content of wine and also to concentrate flavors. Therefore we could assume as functional unit of the two system the quantity of ethyl alcohol inside a bottled wine. With this functional unit the comparison of the two systems in now made considering the alcoholic degree of the red wine and the quality wine respectively of 10% in vol. and 11% in vol. Figure 2 shows the characterization of the two systems assuming the alcoholic degree as functional unit. It can be noted that now the situation is completely inverted; red wine obtained including more technology has a better environmental performance in almost all the impact categories with percentages up to 6.3%. Furthermore, if we consider as function of the system to produce a beverage with a certain alcoholic degree and hedonistic value, the functional unit could be further changed. The hedonistic value is an index which measures the main characteristics of wine based on the traditional describers of the sensory feedback.

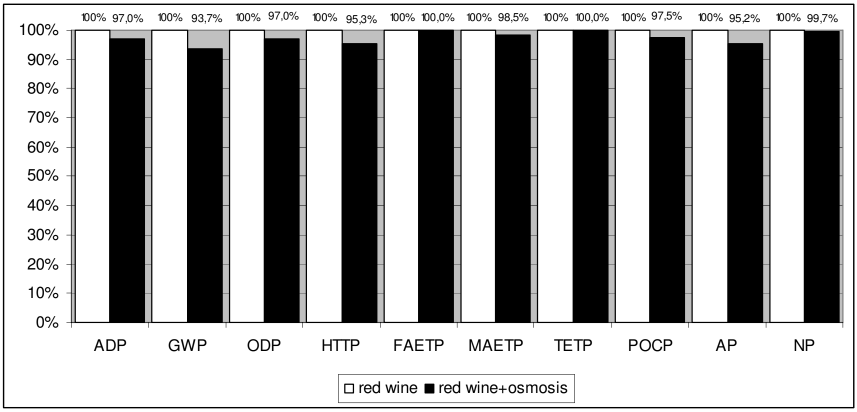

Figure 2: Characterization of the two systems assuming the alcoholic degree as functional unit

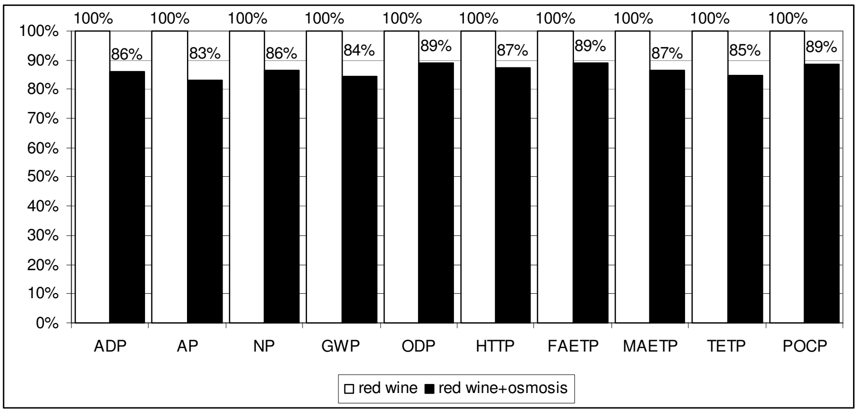

Figure 3: Characterization of the two systems assuming the alcoholic degree and the hedonistic value as functional unit

Figure 3 shows the characterization of the two systems assuming the combination of the alcoholic degree, as previously defined, and of the hedonistic value, with values of respectively 80/100 and 90/100, as functional unit. In this case the better situation is definitely for the quality wine. Other more scientific factors to determine the functional unit could be considered such as the total dry extract, the reducing sugars, the ash content, chlorides and sulphates content, pH, free and total sulphur dioxide, chromatic properties as luminosity and chromaticity, as defined by the EC Regulation 2676/90 and its modifications which determines Community methods for the analysis of wines (EEC, 1990).

3. Conclusions

The analysis has shown the environmental profile of two red wines, comparing a simple wine with a wine obtained through the use of more technology. The results of this study show how the environmental performance of wine production changes if more technologies are used in order to obtain a high quality level wine and how much the results could change if a different functional unit is used. By including more technology in order to produce a quality wine gives the result of a worst environmental performance if the comparison is made on the basis of volume or mass. By considering a different function of the system, such as the production of a beverage with a certain alcoholic degree or a certain hedonistic value, and, consequently, using a different functional unit, the results are completely inverted. This study puts in evidence the enormous importance of functional unit in wine LCA and the need to consider in wine LCA functional units different from mass or volume.

4. References

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Trade-offs between quality and environment in wine production: presentation of a research program for their combined assessment

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ABSTRACT

All stakeholders, from consumers to regulators are beginning to demand that French viticulturists reduce their environmental impact, but not at the expense of the quality of the wine. This position paper presents the approach to evaluate the compatibility of grape quality and environmental objectives in Central Loire Valley PDO (Protected Designation of Origin) vineyards. The environmental quality of vineyard management strategies will be assessed using the LCA method. The adaptations and choices to be made for LCA implementation are discussed. The data handling necessary to build the typology of production strategies and confront both the product and environmental quality of vineyard management are exposed.

Keywords : viticulture, Life Cycle Assessment, grape characteristics, multi criteria rating, functional unit

1. Introduction

Social and economic pressure on the wine sector to adopt sustainability is growing. French government's policy on ecological and sustainable development includes the target of a 50% reduction in the use of pesticides between 2008 and 2018. A new requirement for environmental information on mass consumption products could be imposed after 2012 ("Act Grenelle 2"). This is relevant to the wine sector.

French consumers embrace the tradition and natural aspects of wine and their affinity to it might be eroded by their evolving knowledge of production practices (Brugière, 2009). They are concerned of the risk of agrochemical spraying on crops affecting their diet (Credoc, 2009). The image of wine could be jeopardised by the use in viticulture of 20% of pesticides (in mass) on 3.7% of French UAA (Aubertot *et al.*, 2005). Protected Designation of Origin (PDO) wines embody the localized and traditional technical know-how, but the PDO is a guarantee of origin, but not environmental quality.

The French PDO wine producers are thus faced with this new societal and institutional demand. Similarly, they must take into account the environmental requirements of key international markets. It is then necessary to assist the wine industry in addressing this issue through the evolution of its practices towards being more environmentally friendly. The grape growers of the Loire Valley are seeking support for such development in an environmental practice without damaging the quality of their wines.

This paper introduces the approach implemented in order to provide, to wine sector agents, inputs useful for choosing vineyard management strategies that meet the objectives of product quality and environmental quality. Environmental quality will be assessed by Life cycle assessment (LCA). This project is developed in the frame of the scientific programme

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of UMT Vinitera[1] and targets Loire Valley PDO vineyards. The research is partially funded by Loire Valley Wines Organisation. The originality of this research is situated in product multi-criteria rating of quality and environment, which corresponds to a new research field emerging internationally, and in the adaptation of LCA to the wine grape production.

2. Objectives

This project aims to i) measure the levels of compatibility between indicators of grape quality (Qg) and of environmental quality (Qe) of the vineyard management strategies[2] (VMS) in these attributes ranging from antagonistic to synergistic relationships, ii) to identify, within the VMS, the techniques responsible for these situations, in order to assist wine industry stakeholders in the choice of VMS.

The research strategy intends to i) identify the diversity of existing vineyard management practices, ii) establish a typology of VMS, iii) chose existing vineyard plots representing this diversity as an experimental network, iv) characterize the soil and climate of these plots as co-variables, v) observe the VMS on the plots for three years on the attributes of Qe and Qg, vi) cross Qe and Qp indicators of VMS in a matrix structured in degrees of compatibility, vii) identify the parts of the process playing the main role on the VMS position in the matrix, and viii) adapt the matrix into a tool for wine sector agents.

3. Method

This research focuses on grape production, which represents a significant part of the environmental impacts of wine (Gazulla *et al.,* 2010) and is an important aspect of the quality of the product. One of the two major cultivars of the central Loire Valley: Chenin B. (white) and Cabernet Franc (red) will be utilised. Measurements are planned for 3 consecutive vintages (2010-2012) and will be performed at the plot level (a single unit in the vineyard with homogeneous characteristics). The project will be conducted in conjunction with key stakeholders so it has strong application in the wine sector.

This research is broken down into five stages:

<u>Stage 1: Establishment of the experimental and observational network representing the diversity of VMS of central Loire Valley PDO vineyards *Year 1.*</u>

The diversity of VMS existing in the region is identified by:

- A survey of 67 grape growers with diverse socio-economic profiles, different production systems, from different PDO, in order to describe their VMS on 158 plots.
- A typology of VMS from this survey and existing databases on 40 variables using the data mining platform CORON (Ducatel *et al.*, 2010), and Factorial Multiple Correspondence Analysis (FMCA).

The sample of plots used for the study will be selected by VMS types in order to contrast potential Qe and Qg. Two networks will be designed: one comparing VMS in the same environment (soil, climate) and the other observing VMS in various environments.

<u>Stage 2: Evaluation of Qg and Qe on the selected plots VMS *Years2,3,4*</u>

The evaluation of Qg requires the following:

- The choice of grape quality criteria (biochemical, sensory, physical, microbiological, xenobiotics) through a survey with expert winemakers.

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[1] Unité Mixte Technologique Vins, INnovations, Itinéraires, TERroirs et Acteurs : research unit including staff from INRA-UEVV Angers, ESA- GRAPPE and LARESS research units, IFV- Pôle VdL-C and CTV.

[2] Logic succession of techniques applied on the vineyard by the producer

- The measure of grape quality on the chosen criteria at harvest.

The evaluation of Qe requires the following:

- Adaptation of the LCA method for wine grape production (functional unit, impacts, completion of Eco-invent data base) following the iterative process of LCA.
- Calculation of environmental impacts using LCA (Simapro software, Ecoinvent database).

An inventory of flux data will be made with grape growers once or twice a year depending on their practices traceability.

Stage 3: Evaluation of the compatibility of Qg and Qp for each VMS *years 2,3,4*

The environment (soil and vintage climate) will be characterised as co-variables through existing detailed cartography and annual weather data.

Qe and Qg datasets will be crossed using Multiple Factorial Analysis (MFA) and including environmental co-variables.

VMS will be positioned in a matrix crossing Qg and Qe following the design of:

- A typology of Qg and Qe through a combination of criteria
- A matrix of compatibilities between Qg and Qe using this typology

Stage 4: identification, within VMS, of vineyard management techniques responsible of VMS position in QgXQe matrix *year 4*

The key techniques influencing grape quality will be identified through literature review. The techniques causing the main environmental impacts will be identified both by LCA results on the experimental network and literature.

Stage 5: Development of a tool to assist the wine sector agents in their VMS choices *Year 4*.

The tool will be developed from the matrix.

4. Methodological issues

This approach identifies five main methodological issues. LCA adaptation to the grape production process and the treatment of complex data are the focus of this paper. The relevance of considering 3 vintages for this study is developed in another article (Renaud *et al.*, 2010 (b)). The choice of grape quality indicators to be considered for Qg evaluation and construction of a tool to aid decision making will be developed in a subsequent paper.

LCA has been chosen for the evaluation of the environmental quality of the VMS because it is the most complete tool in the field of global and multi-criteria assessment of environmental impacts. It has recently been chosen, in a simplified form, to assess and display the environmental impact of consumer products in France, which directly concerns the wine industry. However, this method only deals with potential impacts and appropriate models for impacts on biodiversity and soil quality are still under construction. Currently, estimation of the uncertainty of results remains difficult in agricultural LCA (Payraudeau *et al.*, 2005).

The method is currently applied and adapted to agricultural systems and of particular interest to this research, perennial fruit production as well (Mouron *et al.*, 2006). Research utilising LCA in viticulture and oenology has been published (Aranda *et al.,* 2005; Petti *et al.,* 2006; Pizzigallo *et al.,* 2006; Gazulla *et al.*, 2010), but have not addressed the method in detail for application in vineyard management.

Implementation of the method will therefore be needed on aspects specific to vineyard management.

Limits of the system: The assessed product being grape, winemaking process can be ignored provided changes in VMS do not affect the winemaking process impacts or only marginally. In the case of a significant variation of the winemaking phase impacts due to VMS modification, this variation will be identified and quantified to be added to the VMS impacts.

The period considered is the production year from harvest to harvest. Even if in the case of such a perennial plant, back effects of some practices from the past years can affect yield and quality, they will be considered as marginal. We will consider non productive phases of the vineyard (plantation, pulling) as identical for all VMS. They will be simplified and amortized on 25years, usual amortizing duration for vineyard planting in accountancy. However, if important differences between the VMS appear on these phases it will be explored in more details. If the life duration of the vineyard appears to be dependant on VMS the amortizing period will change according to the VMS.

Impacts categories: Viticulture classical practices can cause different impacts on the environment (Renaud *et al.*(a), 2010): water and air pollution from pesticides, soils pollution mainly due to copper spraying on vines for decades, soils erosion because vineyards are often planted on slopes, greenhouse gases production, use of non renewable resources of which fuels take an important part, and biodiversity depletion, mainly due to pesticides use and monoculture.

These key impacts will be considered for the choice of LCA impacts categories.

Choice of Functional Unit (FU): Multifunctionality and specificities of viticulture lead to consider different FU:

- In most cases, yield and quality of grapes, especially sugar and polyphenols content, are negatively correlated. This is even more observed in cool climate vineyards as Loire Valley ones, (Huglin and Schneider, 1998). A FU considering only the mass of production, as usual in agriculture (Hayashi et al. 2005), would disadvantage most qualitative grape production.
- The primary function of grape production is to achieve the best trade-off between a targeted multi-criteria quality level and the highest possible yield, within the limits determined by specifications in PDO areas. It is, therefore, important that FU includes quality parameters associated with yield as Charles *et al.* (1998) propose on wheat.
- Quality objectives are essential in viticulture, and their nature depends on the expected product (white wine, light or full bodied red wine...), The quality parameters included in FU and their levels need to be different according to the type of wine produced.
- Global grape quality could be represented by the monetary value of the grapes. However, the grapes processed on farm, which is a common situation in Loire Valley, are not object of financial transaction. This value could be deducted from the wine value, but the wine value is often not directly correlated to its organoleptic quality, but partly depending on fame of the PDO or of the company. The “financial function” of the grape (Nemecek *et al.*, 2007) won’t be easy to evaluate.
- Vine, as a perennial crop, occupies land for several decades and vineyard has an important function of maintaining space and landscape value (Joliet, 2003). Nemecek *et al.* (2007) measure this “land management function” by hectares time years. Since working at the vintage temporal scale, it seems here inappropriate to include time in the FU.

To estimate the influence of the choice of FU on calculated impacts, LCA calculations will be performed with four different FU: 1kg wine grape, 1kg grape presenting a defined level of quality parameters to be chosen in interaction with wine sector agents and 1ha vineyard. A monetary FU should be defined and tested.

Complex information treatment will be used at three main steps of the project: establishment of the VMS typology and of Qe and Qg typologies and crossing of Qg and Qe of the VMS.

The data from the survey about existing VMS in the Middle Loire Valley vineyard will be completed by recent existing databases describing VMS in the same region and same cultivars, to build VMS typology. The VMS are described in these databases by a list of 100 variables about vineyard management practices. They consist in practices list and their attributes. They include also data on wine quality obtained from the plot, and data on plot attributes (slope, precocity …). Two methods of typology construction will be compared: Factorial Multiple Correspondence Analysis and use of a data mining platform, CORON. Coron platform extracts patterns (frequent, closed, etc..) and then generate association rules (Ducatel *et al.*, 2010).

To identify situations of compatibility or antagonisms between the qualitative and environmental objectives, it is planned to cross Qe and Qg datasets for observed VMS. Both Qe and Qg will be multicriterial. Two methods are considered. The first is a direct statistical treatment of the data sets through Multiple Factorial Analysis (MFA) (Escofier and Pagès, 1998). MFA is a method of analysis of multiple tables in which individuals are described by several groups of quantitative or qualitative variables. The second is the construction of a matrix where the VMS will be situated according to their Qe and Qg types. This implicates the definition of, in one hand, a typology of grape qualities based on combinations of different quality criteria levels, and in the other hand, of a typology of environmental qualities also based on combinations of different levels of the impacts assessed by LCA. The plot environment (soil, climate) needs to be taken into account as a co-variable, for it has a strong influence on yield and grape quality.

5. Conclusions

The expected results are i) the identification of VMS diversity, ii) a built typology of Loire Valley VMS for the studied cultivars, iii) an operational method to characterize VMS by the relationship between Qe and Qg, iv) the positioning of each VMS type within the QeXQg matrix, structured in increasing degrees of compatibility, v) a list of the vineyard management techniques responsible for this position in the matrix VMS QeXQg, vi) an advisory tool developed with the actors from this matrix, vii) adapted LCA method for grape production processes in the Loire Valley, viii) results of methodological development on LCA which should benefit viticultural scientists and technicians wanting to use LCA for wine grape production. This work should also contribute to improve multi criteria methods for production processes evaluation.

These results should provide the wine industry the opportunity to increase its awareness of environmental issues and to further increase the environmental quality of grape production processes. The findings could contribute to changes in viticulture towards more environmentally friendly practices. This research could propose new tools for actors in charge of advising the wine sector and enable them to better integrate environmental objectives into the specifications of labelled productions, including PDO, in line with consumers and societal expectations.

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Interpretation of Life Cycle Assessment results using a multi-criteria tool: application to the olive oil chain

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ABSTRACT

One of the main uses of LCA is the identification of environmental improvement options of products/processes but in comparative analysis of similar systems, LCA studies often produce uncertain results, so it could be a complex task to select the product with the best environmental performances. Decision theory tools would be useful to the understanding of the LCA results and, within these, multi-criteria methods provide a flexible tool that is able to handle and bring together a wide range of variables appraised in different ways and thus offer valid assistance to the decision-maker in mapping out the problem. This paper highlights how multi-criteria methods would be beneficial in order to further improve LCA as a tool for decision making and to this purpose, the joint use of LCA and multi-criteria algorithm was developed and the validity and feasibility of this approach was tested with applications in olive oil production.

Keywords: Multi-criteria methodology, LCA, Decision-making tools, Integrated tools, Olive oil production,

1. Introduction

The new international standards for Life Cycle Assessment ISO 14040:2006 and ISO 14044:2006 point out that there is no single solution as to how LCA can best be applied within the decision-making context (Finkbeiner et al., 2006): it depends on various aspects such as applications, products, strategy and so on.

This gives rise to the need to develop a management tool that can assist the decision maker in assessing a set of scenarios from different viewpoints and to choose the option of *compromise*, namely the one held to be most acceptable by all the criteria considered altogether. The search for a *best compromise* solution requires a suitable assessment method and the various multi-criteria methods available seem best suited to such a purpose. The idea is to develop a model that integrates the results of an LCA to a multi-criteria algorithm in order to obtain a ranking of scenarios: from the best to the worst. In the paper: the next section outlines the multi-criteria method used (Promethee I and II), section 3 describes the olive oil chain and the scenarios proposed, section 4 explains the empirical analysis and the results achieved.

2. The multi-criteria methodology

Multi-criteria methods provide a flexible tool that are able to handle and bring together a wide range of variables appraised in different ways and thus offer valid assistance to the decision maker in mapping out the problem.

One of the various multi-criteria methods is the outranking approach, which proceeds by a pairwise comparison of alternatives for each single criterion in order to determine partial binary

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relations denoting the strength of preference of alternative *a* over alternative *b*. Outranking approaches are not based on an underlying value function.

The output of an outranking analysis is not a value for each alternative but an outranking relation specific to the set of alternatives.

The method of outranking called PROMETHEE (Preference Ranking Organization Method of Enrichment Evaluation) devised by Brans J.P. et al. (1985, 1986, 1994, 1998) is here used.

The following procedure is recommended to implement the method (Cavallaro, 2009):

Step 1 (calculation of multi-criteria preference index): The degree of preference of an alternative a_i in comparison to a_m is expressed by a number between 0 and 1 (from 0 indicating no preference or indifference up to 1 for an outright preference). When the pairs of alternatives a_i and a_m are compared, the outcome of the comparison must be expressed in terms of preference in the following way (*Brans et al.,* 1986): $P_k(d) = 0$ means there is indifference between a_i and a_m or no preference; $P_k(d) \cong 0$ expresses a weak preference for a_i over a_m; $P_k(d) \cong 1$ strong preference for a_i over a_m; $P_k(d) = 1$ outright preference for a_i over a_m. In practice this preference function $P_k(d)$ represents the difference between the evaluation of the two alternatives, thus it can be expressed as follows (*Brans et al.,* 1998):

$$P_k(a_i, a_m) = P_k[d(a_i, a_m)]$$
$$P_k(c_k(a_i) - c_k(a_m)) = P_k(d) \in [0,1] \tag{1}$$

Therefore the decision maker assigns a set of weights $W=(W_1,W_2,\ldots W_n)$ to the *n* criteria. The weights represent the relative importance of the criteria used for the assessment; if all criteria are equally important then the value assigned to each of them will be identical. In addition to weighting the method involves setting thresholds that delineate the decision maker's preferences for each criterion and the critical thresholds are thus: the indifference threshold q_i and the preference threshold p_i (a more exhaustive description of the procedure can be found in the literature).

The index of preference Π is calculated for each pair of actions a_i and a_m as the weighted average of preferences calculated for each criterion. The index Π is therefore defined as follows (Brans *et al.,* 1986):

$$\prod(a_i, a_m) = \frac{\sum_{k=1}^{K} w_k \cdot P_k(c_k(a_i) - c_k(a_m))}{\sum_{k=1}^{K} W_k} \tag{2}$$

Step 2 (ranking the alternatives):the traditionally non-compensatory and methodologically important models include ones in which preferences are aggregated by means of outranking relations. Outranking is a binary relation *S* defined in *A* such that $a_i S a_m$ if, given the information relating to the decision maker's preferences, there are enough arguments to decide that "a_i is at least as good as a_m" while there is no reason to refute this statement, i.e. $a_i \mathrm{Sj} a_m$ implies $a_m \mathrm{Sj} a_i$. Positive and negative flows, used to rank the alternatives, are defined as follows (Brans *et al.,* 1994):

$$\Phi^+(a_i) = \frac{1}{n-1} \cdot \sum_{x \in A} \Pi(a_i, a_m) \tag{3}$$

This indicates a preference for action a_i above all others and shows how 'good' action a_i is (positive outranking flow).

$$\Phi^-(a_i) = \frac{1}{n-1} \cdot \sum_{x \in A} \Pi(a_m, a_i) \tag{4}$$

This indicates a preference for all the other actions compared with a_i and shows how weak action a_i is (negative outranking flow).

Finally a_i outranks a_m if:

$$\Phi^+(a_i) \geq \Phi^+(a_m) \text{ and } \Phi^-(a_i) \leq \Phi^-(a_m) \quad (5)$$

Equality in Φ+ and Φ- indicates indifference between the two compared alternatives. Under the Promethee I method some actions remain incomparable, in the case that a complete preorder is required that eliminates any incomparable items, then Promethee II can give a complete ranking as follows (Brans *et al.,* 1986):

$$\Phi^{net}(a_i) = \Phi^+(a_i) - \Phi^-(a_i) \quad (6)$$

The net flow is the difference between the out-flow and the in-flow.

3. Application to olive oil chain scenarios

The integration approach described in the previous section was applied to the olive oil chain comparing eight scenarios of olive oil production with cradle-to-gate LCA analysis. The scenarios are compared according to the same functional unit: *1000 kg of olives* and include all the direct and indirect activities which are necessary to produce olive oil. In particular, the main phases included in system boundaries are: agricultural phase, oil production phase and waste treatment phase. Plant breeding, life cycle of machineries and other phases (such as transport, packaging, distribution, etc.), being common to the systems, have been omitted in this comparative study. The system scenarios differ for cultivation type, oil extraction methods and olive mill waste treatments. Relating to cultivation type, conventional or organic systems were considered and it was assumed that the different agricultural practices cause a lower productivity of organic fields of about 1/3 compared to conventional ones. Relating to oil extraction methods, the analysis includes:

- c*ontinuous centrifugation with a three-phase system* that generates olive husk (OH), olive oil and Olive Mill Wastewaters (OMW),
- *continuous centrifugation with a two-phase system* that allows separation of oil from olive paste without addition of water and this leads to removal of the problem of vegetable water. The two-phase system generates only olive oil and a semi-solid waste called Olive Wet Husk (OWH),
- *destoning process* – in this case stones are removed before kneading, improving the quality of olive oil (better sensory qualities and shelf-life).

Relating to olive mill waste treatments, the following assumptions were made:

- *Olive Mill Wastewaters* (OMW), deriving from the three-phase system are the main pollutant mill waste. The treatment methods of OMW considered in this analysis are direct application on soil and composting (this method allows the return of nutrients to cropland and avoids the negative effects previously cited when OMW is directly applied to soil.)
- *Olive Husk* (OH), deriving from the three-phase system, is usually sent to oil factories (after a drying process, oil is extracted using hexane; the process allows us to obtain oil, exhausted olive husk and stones used as fuel), but it could also be co-composted with OMW (co-composting of OH and OWH with other agricultural wastes such as straw, leaves, etc.);
- *Olive Wet Husk* (OWH), deriving from the two-phase system, generates OWH, which includes olive vegetation waters and this causes a high moisture content that creates great difficulties for treatment in oil factories, so co-composting of OWH with manure is considered in this analysis.

Considering the differences stated above and available data, the following scenarios were analysed:

- *Scenario A (SA)* includes: *organic olive tree cultivation* (drip irrigation; fertilization with manure and compost of destoned OWH deriving from a two-phase mill; biological pest control, diesel and lube oil consumption; burning of pruned wood); *oil extraction with a two-phase system and destoning process* (olive stones obtained are considered as an avoided production of a conventional fuel); *co-composting of destoned OWH with manure* (compost obtained is considered as an avoided production of a conventional fertilizer).

- *Scenario B (SB)* includes: *conventional olive tree cultivation* (drip irrigation; fertilization with chemical fertilizer and compost of de-stoned OWH deriving from a two-phase mill; conventional pesticide treatment; diesel and lube oil consumption; burning of pruned wood); *oil extraction with a two-phase system and destoning process* (olive stones obtained are considered as an avoided production of fuel); *co-composting of destoned OWH with manure* (compost obtained is considered as an avoided production of a conventional fertilizer).
- *Scenario C (SC)* includes: *organic olive tree cultivation* (drip irrigation; fertilization with manure and soil spreading of OMW deriving from a three-phase mill; biological pest control; diesel and lube oil consumption; burning of pruned wood); *oil extraction with a three-phase system*; *oil-husk extraction mills* (exhausted OH and stones are avoided productions of fuels).
- *Scenario* D (*SD*) includes: *conventional olive tree cultivation* (drip irrigation, fertilization with chemical fertilizer and soil spreading of OMW deriving from a three-phase mill, conventional pesticide treatment, diesel and lube oil consumption, burning of pruned wood); *oil extraction with a three -phase system*; *oil-husk extraction mills* (exhausted olive husk and stones obtained are considered as avoided production of conventional fuels).
- *Scenario* E (*SE*) includes: *organic olive tree cultivation* (drip irrigation; fertilization with manure and compost of OWH deriving from a two-phase mill; biological pest control, diesel and lube oil consumption; burning of pruned wood); *oil extraction with a two-phase system*; *co-composting of OWH and manure* (compost obtained is considered as an avoided production of fertilizer).
- *Scenario* F (*SF*) includes: *conventional olive tree cultivation* (drip irrigation; chemical fertilization and compost of OWH deriving from a two-phase mill; conventional pest treatment; diesel and lube oil consumption; burning of pruned wood); *oil extraction with a two-phase system*; *composting of OWH and manure* (compost obtained is considered as an avoided production of fertilizer).
- *Scenario* G (*SG*) includes: *organic olive tree cultivation* (drip irrigation; fertilization with manure, compost of OH with OMW and soil spreading of remaining part of OMW deriving from a three-phase mill; biological pest control; diesel and lube oil consumption; burning of pruned wood); *oil extraction with a three-phase system*; *co-composting of OH and OMW* (compost is considered as an avoided production of fertilizer and stones as avoided production of fuel).
- *Scenario* H (*SH*) includes: *conventional olive tree cultivation* (drip irrigation, chemical fertilization, compost of OH with OMW and soil spreading of remaining part of OMW deriving from a three-phase mill, conventional pest treatment, exhausted OH, burning of pruned wood); *oil extraction with a three -phase system*; *co-composting of OH and OMW* (compost obtained is considered as an avoided production of fertilizer and stones as avoided production of fuel).

The data has been taken from scientific literature (De Gennaro et al., 2005, Roig et al., 2006; Salomone et al., 2009; Vlyssides et al., 2004,) and from the LCA database SimaPro (PrèConsultant, 2008). The emissions connected to the use of fertilizers have been quantified following Brentrup et al. (Brentrup et al., 2000). The emissions of pesticide to air and soil have been assessed following Birkved and Hauschild (Birkved, Hauschild, 2006). The life cycle impact assessment was achieved using the CML 2000 approach and characterization results are reported in table 1.

4. Results and conclusions

Table 1 shows the matrix containing the scenarios and how these perform with respect to the evaluation criteria (impact categories) selected. Normally, this matrix also contains the weights assigned to the various criteria. How to attribute weights to the criteria remains one of the greatest weaknesses of this methodology, so we decide to assign equal weights to all criteria. As regards the indifference and preference thresholds we decide to assign for each criterion q_i=1.5% and p_i= 3% (level criterion). Two distinct rankings of alternatives are computed and displayed. The first one is PROMETHEE I, which gives a partial ranking. It is based on strongly established preferences, so some actions remain incomparable under this method.

Table 1: Scenario analysis - characterization results (CML 2000)

Impact category	Unit (kg)	Scenario A	Scenario B	Scenario C	Scenario C	Scenario D	Scenario E	Scenario F	Scenario G
Ozone layer depletion	*CFC-11eq*	1,35E-03	4,56E-04	1,02E-03	3,00E-04	1,42E-03	5,18E-04	1,27E-03	3,73E-04
Photochemical oxidation	*C2H4*	-2,33E-02	-2,20E-02	9,98E-01	8,58E-01	9,73E-02	9,86E-02	1,39E-02	1,26E-02
Terrestrial ecotoxicity	*1,4-DBeq*	4,27E+00	3,42E+00	3,82E+00	3,62E+00	4,09E+00	3,11E+00	3,73E+00	3,18E+00
Abiotic depletion	*Sbeq*	-9,40E+00	6,96E+00	4,45E+00	1,36E+01	-8,18E+00	8,18E+00	-1,86E+01	-2,42E+00
Acidification	*SO2eq*	3,77E+00	1,00E-02	1,58E+01	4,61E+00	1,78E+00	-2,06E+00	-2,47E+00	-5,94E+00
Fresh water aqu. ecotox.	*1,4-DBeq*	1,33E+02	9,86E+01	1,03E+02	1,18E+02	1,46E+02	1,02E+02	9,49E+01	9,07E+01
Eutrophication	*PO4--eq*	1,51E+02	1,32E+02	1,53E+02	1,34E+02	1,51E+02	1,32E+02	1,52E+02	1,33E+02
Global warming	*CO2eq*	-3,66E+03	-1,39E+03	1,01E+03	5,16E+02	-4,28E+03	-2,01E+03	-6,46E+03	-4,24E+03
Human toxicity	*1,4-DBeq*	3,78E+02	4,10E+02	1,48E+03	1,56E+03	5,82E+02	6,09E+02	6,26E+02	6,75E+02
Marine aquatic ecotox.	*1,4-DBeq*	2,45E+05	1,49E+05	1,94E+05	1,21E+05	2,43E+05	1,47E+05	2,30E+05	1,34E+05

Table 2 presents the results regarding preferences (leaving and entering flows) of the various alternatives expressed numerically. Fig. 1 graphically illustrates the positions of each alternative in the final ranking and it is immediately apparent that the best performers are: S_H, S_E, S_A and S_G while S_F is incomparable with S_B; finally the worst scenario is represented by S_C. Table 3 (weight stability intervals) shows the limits within which the weight of each criterion can be modified without changing the order of the PROMETHEE II complete ranking (fig. 2).

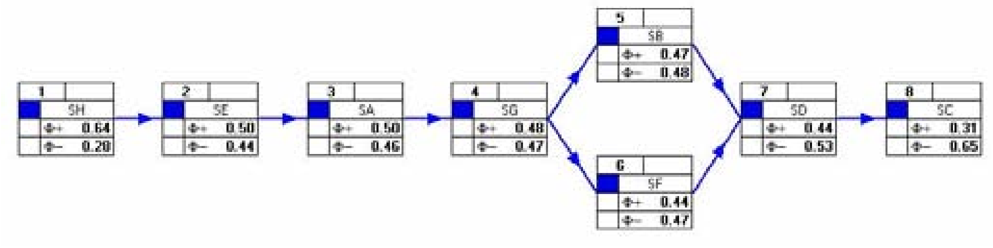

Figure 1: Partial Ranking

This information is of interest for assessing the general robustness of the ranking and useful for performing a sensitivity analysis. The best position of scenarios (S_H) (conventional cultivation) in the final ranking mainly depends on a low land use intensity with respect to the final output of the production activity. Scenario S_H is followed by a group of organic alternatives S_E, S_A and S_G, while the worst environmental performance is related to the scenarios in which a conventional cultivation is applied with a greater use of pesticides, water and chemical fertilizers. As this study demonstrates, multi-criteria analysis can provide a technical-scientific decision making a support tool that is able to justify its choices clearly and consistently. Besides, the experiment of a joint LCA and multi-criteria approach appears to be very interesting.

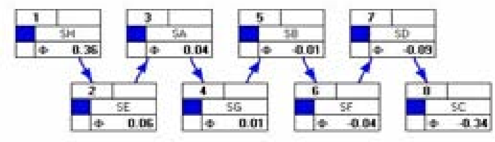

Figure 2: Complete Ranking

Table 2: Preference flows and ranking

	Φ^+	Φ^-	Φ	**Ranking**
S_H	0.6429	0.2786	0.3643	1
S_E	0.5000	0.4429	0.0571	2
S_A	0.5000	0.4571	0.0429	3
S_G	0.4786	0.4714	0.0071	4
S_B	0.4714	0.4786	-0.0071	5
S_F	0.4357	0.4714	-0.0357	6
S_D	0.4357	0.5286	-0.0526	7
S_C	0.3143	0.6500	-0.3357	8

Table 3: Weight stability intervals

Criteria	Weight	Stability interval	
		Min	Max
Ozone layer depletion	1	0.9286	1.1667
Photochemical oxidation	1	0.7500	1.1111
Terrestrial ecotoxicity	1	0.7500	1.0714
Abiotic depletion	1	0.8750	1.5000
Acidification	1	0.9167	1.2000
Fresh water aqu. ecotox.	1	0.9286	1.2500
Eutrophication	1	0.0000	1.1333
Global warming	1	0.9000	1.4167
Human toxicity	1	0.8571	1.1818
Marine aquatic ecotox.	1	0.7917	1.0714

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Orange juice, which one should I drink?

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ABSTRACT
Consumers' decisions can have a great influence on the environmental impacts through the food chain. This means that by choosing similar products (with the same benefit for the consumer) the environmental impact can be diminished. The goal of this paper is to compare the energy use in the life cycle of orange juice made from oranges from different origins and processed in different ways. The oranges were grown in Spain and Brazil and processed at home or in the country of origin. Preliminary results showed the high energy use in orange cultivation, with differences in the two cropping systems. On the one hand, oranges in Comunidad Valenciana (Spain) are produced in an intensive way and mainly focused for fresh consumption, thus low grade oranges are processed as orange juice. On the other hand, Brazilian oranges are grown for being processed and agricultural practices are not so intensive. Regarding the processing system, home processing has a lower impact that processing in a factory.

Keywords: orange juice, origins, agriculture, processing, energy

1. Introduction

As consumers we can choose between homemade orange juice from fresh oranges and orange juice from reconstituted concentrated juice that, at the same time, can be imported from overseas or not. What *a priori* could seem a matter of preferences has however environmental consequences. In fact, an according to the results of a project founded by the EU, food is one of the consumption groups with a higher impact throughout its life cycle (Tukker et al., 2006). For this reason, consumers have a big influence on the impacts derived from foods and this means that by choosing similar products (with the same benefit for the consumer) the environmental impact can be diminished.

Related to this, in the last years an ongoing debate about the convenience or not of regionalization versus globalization of alternative food systems has emerged (Schlich and Fleissner, 2005; Blank and Burdick, 2005; Sim et al., 2006; Milà i Canals et al., 2007). Although generally the consumption of regional products is recommended (Jungbluth et al., 2000) they are not always environmentally preferable (Schlich and Fleissner, 2005). From the above mentioned studies, it can be said that apart from the transport distance, there are other factors influencing the choice of food products such as the agricultural intensification, scale of production, background technologies such as for electricity, storage, etc.

Brazil is the first orange producing country in the world, with a total planted area of around 830,000 hectares in 2008 (Faostat, 2010). More than 70% of the orange crop is processed into frozen concentrated orange juice (FCOJ) and exportations of FCOJ represent around 97% of the total production (Coltro et al, 2009). In fact, Brazil exported around 60.000 t of oranges and 987.000 t of FCOJ between the years 2000 to 2009 (Citrus Br, 2010). Spain is the seventh orange producer in the world, (Faostat, 2010). Around 8.6 million tons of citrus were produced in 2008 (MARM, 2010) from it around 3.9 million tons were produced in the Comunidad Valenciana (CAPA, 2008). The main market of Spanish

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oranges is eastern and central Europe and the USA: exports to the USA, Switzerland, Russia and Norway represent around 80% of the exportations. Thus the most of the oranges are sold for fresh consumption and only second category oranges are addressed to orange juice production.

The goal of this study is to carry out an analysis of primary energy use to verify if the agricultural intensification has a bigger influence than transport distance or if on the contrary, production efficiency and transport logistic are more important from the energy point of view in different ways to produce orange juice.

2. Methodology

Four scenarios in orange juice production have been studied:

1- Production of fresh orange juice in Spain with household juice extractor and using oranges for fresh consumption grown in Valencia (Spain).
2- Production of fresh orange juice in Spain with household juice extractor and using oranges grown in Sao Paulo (Brazil). This can happen between May and October, when Spanish oranges are not available.
3- Production of orange juice reconstituted from FCOJ made in Spain with local oranges.
4- Production of orange juice from FCOJ imported from Brazil and reconstituted in Spain.

In this study primary energy use (Cumulative Energy Demand, CED) has been used as an indicator for environmental impacts; CED has demonstrated its adequacy in many cases as a screening indicator for environmental performance (Huijbregts et al., 2006). The functional unit to which the results have been referred is 1 kg of orange juice ready to drink. Figure 1 shows the system boundaries considered in the scenario scenarios, neither the distribution and consumption of the juice nor the waste treatment was considered.

The agricultural production of oranges considers a productive season. It includes the production of agricultural inputs (pesticides only for Spanish oranges and fertilizers in both cases, Spain and Brazil) and the production and use of energy for watering and machinery use. For Spanish oranges (scenarios 1 and 3) data from Sanjuán et al. (2005) have been used. Among all the scenarios analyzed in Sanjuán et al. (2005) as reference for this study an average farm of *navelina* variety, based in no tillage, with drip irrigation using underground water has been considered. In the case of Brazil (scenarios 2 and 4), data from a study on FCOJ carried out by Coltro et al. (2008) has been used. This study evaluated the agricultural production of *Pêra, Valência* and *Natal* oranges in the Northern and Southern regions of the State of São Paulo.

It must be taken into account that orange farms are multifunctional systems, since they produce different quality orange that have different uses. In the case of Spain scenarios, the oranges are transported after harvesting to a central where they are sorted out in those aimed to fresh consumption (77% of the harvested oranges, in mass), those with stable defects (15.5%), which are used for juice production, and those with unstable defects (7.5%) that are used to produce fodder. Taking these data into account a mass allocation has been made for orange production in farms.

In scenarios 1 and 3, the postharvest treatment in a fruit central has also been included. There the oranges are sorted out and then those for fresh consumption (scenario 1 oranges) are packaged, and stored in chambers for an average time of 3 days previous to its distribution in supermarkets.

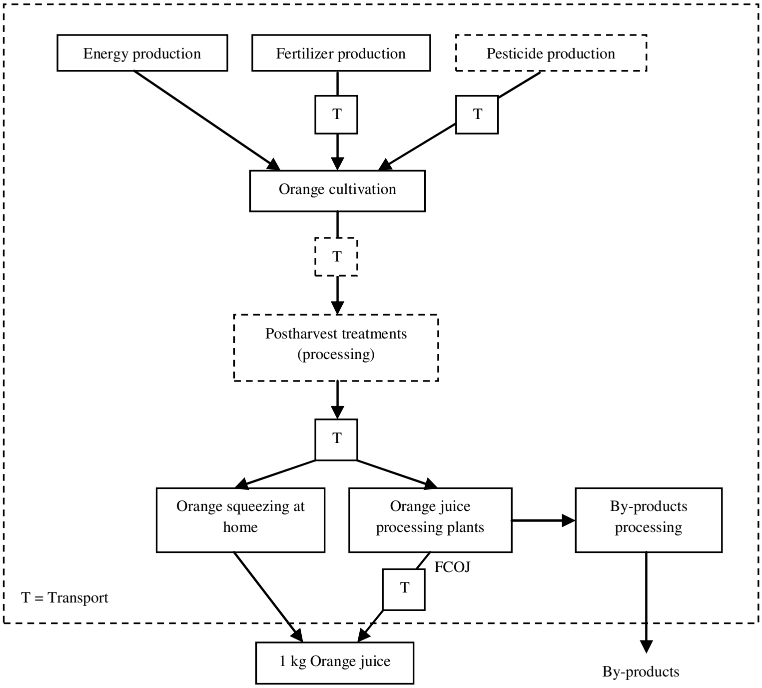

Figure 1: System boundaries considered in this study. Functional Unit: 1kg of orange juice. The broken line shows those steps that are only carried out in scenarios 1 and 3.

In order to obtain the energy consumption for orange squeezing experiences with different juice extractor models have been carried out.

For scenario 3, production of FCOJ in Spain, data provided by Indulleida S.A. have been used. 20% of the oranges processed in that company are those for fresh consumption (77% allocation) and the 80% are the ones set aside for juice (15.5% allocation). The yield of fruit squeezing is around 40-45 kg juice/100 kg fruit. For juice pasteurization a power consumption of 90 - 100 kWh· fruit t^{-1} and 2 t of steam·h^{-1} have been considered, with a processing capacity of 10.000-15.000 L juice·h^{-1}. The juice is concentrated to 65ºBrix in a three effect evaporator with a yield of 5-6 kg juice·(kg of concentrated)$^{-1}$ and a steam consumption of 4 t·h^{-1}. The saturated steam (345 kPa) is generated in a boiler with natural gas combustion. Data for energy consumption in the boiler has been obtained from Jiménez-González and Overcash (2000). Furthermore, in scenario 3, the energy consumption for processing the following by-products has also been considered: essential oils, orange cells and fiber pellets. All these data were obtained from machinery specifications and *in situ* measurements.

For scenario 4, the data obtained by Coltro et al. (2008) in their study on the production of FCOJ in Brazil have been used. The system evaluated included orange-growing at commercial farms (fertilizers production and energy production for watering systems and farm machinery), harvesting, storage, transport by trucks to the processing plants, and orange processing to FCOJ and by-products. In scenarios 3 and 4, the juice is packaged in a Liquid Paper Board.

Regarding the transport, in scenario 1 the oranges are transported from the fruit central located in Valencia region to the consumption point, that has been supposed in Valencia (for each scenario). For scenario 2, the usual exportation route has been supposed, transport by refrigerated truck from the factory to the freight terminal of from Porto do Santos (Sao Paulo State, Brazil); from there to Antwerp (Belgium) the oranges are transported in boats with refrigeration system and finally from Antwerp to Valencia by refrigerated truck. In scenario 3, the oranges travel from the fruit central to the factory (located in Lleida) and from the factory to Valencia. In the case of scenario 4, to the energy calculated by Coltro et al. (2008) it has been added the one needed to transport the FCOJ from Brazil to Spain according to the same exportation route has been added, but taking into account the energy needed to keep the frozen juice. For the energy calculation of boat transport the data of Blanke and Burdick (2005) have been used.

3. Results

Figure 2 shows the results obtained for each processing step for the four scenarios, expressed as MJ per kg of ready to drink juice (functional unit of the study), either fresh or reconstituted.

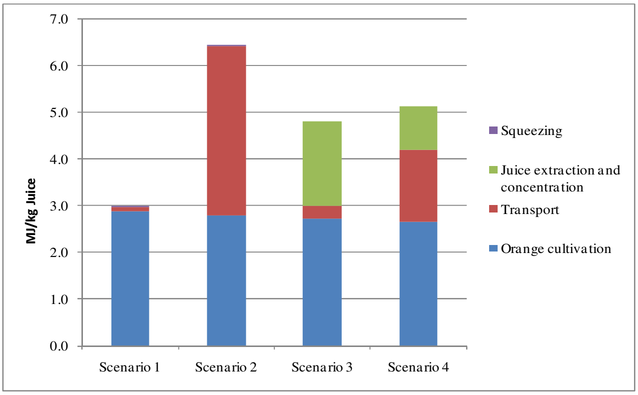

Figure 2: Energy consumption (MJ) for 1 kg of orange juice: scenario 1 “fresh juice from Spanish oranges”; scenario 2 “fresh juice from Brazilian oranges”; scenario 3 “juice from FCOJ made in Spain”; scenario 4 “juice from FCOJ from Brazil”.

Regarding the agricultural stage, it can be observed that scenarios 2 and 4 (Brazilian production of oranges) have the lowest energy consumption. Scenarios 1 and 3 differ because the allocation factor (higher for scenario 1, oranges for fresh consumption) and also because in scenario 1 packaging and refrigeration of the oranges are included. It is also important to notice that in the Spanish scenarios the manufacturing of the pesticides has also been included, although it supposes a small percentage of the total.

It has to be pointed out that although there are not detailed data of the agricultural phase in scenarios 2 and 4 in the source study (Coltro et al, 2008), according to other literature data the orange yield is similar in both countries, 30.500 kg orange/ha in Brazil (Coltro et al. 2009) and 30.000 kg orange/ha in Spain (Sanjuán et al., 2005). With respect to the intensification of agricultural practices, the fertilizer doses in Spain are 291 kg N/ha, 74.7 kg K/ha and 39.6 kg P/ha (Sanjuán et al., 2005), while in Brazil, according to the Fertilizer Use Statistics of Fertistat (FAO, 2007), these are 55 kg de N/ha, 24 kg de P/ha and 45 kg de P/ha. Other possible difference between Spanish and Brazilian scenarios could be the mechanization degree, since average farms in Valencia are very small (around 6 ha on the average) and farm works are not very mechanized.

As expected, the transport stage in scenarios 2 and 4 present higher energy consumption since the transport distance is also higher. The differences found between scenarios 2 and 4 are due to the fact that in scenario 2 the amount of oranges needed for making 1 kg of juice, that is around 2 kg, is transported while in scenario 4 the concentrated juice needed for further reconstitution is transported, that is around 0.2 kg of FCOJ.

Regarding the orange processing, squeezing the oranges at home has very low energy consumption. The processing of the by-products, or waste treatment in this case, has not been included because it has been considered that it is composted, thus it is an avoided process. With respect to scenarios 3 and 4, in which the juice is extracted, concentrated and reconstituted, the energy consumption in scenario 3 is considerably higher than in scenario 4. It has to be pointed out that the production of the juice in scenario 3 implies 0.54 MJ/kg reconstituted juice, the rest of the energy is consumed for the processing the by-products. By-products processing has also been included in scenario 4 but there is not available information of the processing methods applied.

Transport is the main cause of the energy consumption per kg of juice in scenarios 2 and 4. Between the two Spanish scenarios, scenario 1 is preferable from the environmental point of view, independently of the organoleptic quality and consumer preferences. For this reason, from the energy point of view, the consumption of orange juice made at home with oranges of the region is preferable.

Nevertheless, as it has been pointed out in the text, some doubts with respect to the compared scenarios arise, since they come from different sources, with the subsequent problem when carrying out eco-labels, carbon footprint studies, etc. Furthermore, taking into account the comparative character of this study, it would be interesting to perform an uncertainty analysis, but this is a first approach to the study and it is planned to do it.

In spite of the coordinating will of both the LCA methodology and the present study, it is unavoidable to make some assumptions and generalizations that can question the validity of the results. For example, the varieties of oranges considered are different and the processing of the by-products is also different. In conclusion, and in order to have really representative and comparable LCA and food miles studies in the future, an harmonization of data and system boundaries should be pursed. As Basset-Mens (2008) pointed out this would require the creation of international working groups per product category and the progressive definition of consistent and harmonized methods and data across all the studies.

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LCA applied to agro-industrial products: the case of the vegetable oils in Tuscany

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ABSTRACT

During the last years, Tuscany policies have promoted a preservation of agricultural landscape and environment. In fact, food products with high quality level are strictly linked with the land where they are cultivated: establishing adequate methodologies that will quantify and evaluate the environmental sustainability associated with the agricultural production chains is needed. With the aim to achieve this objective the LCA methodology has been adopted for the production of some vegetable oils, i.e. sunflower oil and olive oil, evaluating two environmental impacts: the CO_2 equivalent emissions and the primary energy consumption. The LCA results for the vegetable oils production have shown that the CO_2 equivalent emissions are mainly determined by the agricultural phase. Therefore, data with high quality level are needed for the cultivation phase in order to assure a better implementation of the LCA and consequently promote the development of some environmental certifications for the agricultural products.

Keywords: Life Cycle Assessment, greenhouse gases emissions, primary energy consumption, vegetable oils

1. Introduction

Over the last decade the agriculture role and consequently the farms' role has slowly changed. Originally farms were only considered as a technical-economic unit consisting of land, where the agricultural, forestry or zootechnical production would be implemented; now farms have important functions in terms of landscape conservation, land coverage and environmental protection by various types of pollution. These functions have been associated to farms not only by national and European policies but also by market needs: Tuscany agricultural products are characterised by high quality and usually the alimentary function is linked with the culture of the specific territory in which they are produced.

Tuscany agriculture, particularly agriculture with high quality level of products, has always referred to a market which is constituted for a large part by foreign customers. These customers buy not only a food product but also the cultural message associated with it; therefore, during the last years regional planning policies have strictly promoted a preservation of landscape and environment, where agricultural products are cultivated. Therefore, establishing adequate methodologies that will quantify and evaluate the environmental sustainability associated with agricultural production chain is needed, also hypothesising in the future some kind of environmental certifications to be used as added value together with those of quality. With the aim to achieve this objective the Life Cycle Assessment methodology has been adopted, not without some difficulty: agricultural processes are properly extremely het-

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erogeneous due to the variety of environments in which crops grow, to the different typologies of cultivars of each crop, to the various levels of mechanization in field, to the residues management, etc. (Avraamides et al., 2008; Chiaramonti et al., 2009; Chiaramonti et al., 2010; Dessane, 2003).

The proposed work has concerned the production of some vegetable oils, i.e. sunflower and olive oils, estimating CO_2 equivalent emissions and primary energy consumption. These environmental impacts have been used as an early indicator for the sustainability level of the chains, an approach which can also constitute a first step for a more ambitious environmental certification of the agricultural products. Anyway, the main result of the work has been the acquisition of several data concerning material and energy flows for the analysed agricultural chains.

2. Data inventory

Basing on data of the 5th Agricultural Census developed by ISTAT in the Vth Agricultural Census 2000, the Tuscany region is characterised by a land use which promotes olive-groves (18% of the total arable land) and vineyards (11% of the total arable land). Moreover, during the last years the relevance of industrial crops like sunflower and rapeseed is more and more increased, also due to the possibility to produce biofuels (Recchia et al., 2008). Considering all these assumptions, the work has concerned the production of two different vegetable oils: sunflower oil and olive oil. Sunflower oil is an agricultural product both for the food and the non-food sector: this oil can be alternatively used as alimentary oil and biofuel, therefore its production can be considered as strategic for the regional policies. On the other hand olive oil is a traditional product in Tuscany characterised by high quality and high market value, which may cause relevant pressures on the environment because of by-products originated during the extraction phase (i.e wastewater and husk).

The farms and the agro-industries involved in the work have been:

- four farms for sunflower cultivation: Tommasi Luca (Pisa), Poggio Bonelli srl (Siena), Mondeggi Lappeggi srl (Firenze), Giorni Primo (Arezzo);
- Montepaldi farm, where a decentralised extraction plant for sunflower oil is present;
- three agro-industries for olive oil production: Frantoio Grevepesa, with a large sized extraction plant collecting olives of numerous local farms; Azienda Buonamici, characterised by organic olive-groves in hilly areas, with a small sized extraction plant; Castello di Fonterutoli, with a small sized extraction plant.

2.1. Definition of the agricultural chains

The scope of the LCA is evaluating the environmental impacts associated with the vegetable oils production. Particularly, for the two production chains studied it is possible to indicate:

- as functional unit, a kg of vegetable oil;
- as physical boundaries, boundaries able to include the agricultural and the extraction processes of the oils, as illustrated in Figures 1 and 2. Particularly, the sunflower oil chain has not included in its boundaries the final destination of the cake produced during the extraction phase because all the scenarios considered hypothesise the reuse of the cake as animal feed;
- as method to evaluate the co-products contributions, the substitution method with a system expansion;

- as system under investigation, an agricultural practice that is considered to be typical for Italian conditions, i.e. without adapted fertilisation;
- as impact categories, the CO_2 equivalent emissions (considering CO_2 with GWP=1, N_2O with GWP=298, CH_4 with GWP=25) and the CER (Cumulated Energy Requirement) evaluating the primary energy consumption as defined in the software GEMIS 4.5.

2.2. Description of data collection

This phase has been realised carrying out a literature review (ENAMA, 2005; Recchia et al., 2007; Regione Umbria, 2006; Riello, 2006; Riva, 1996; Venturi et al., 2003) and collecting experimental data in some Tuscany farms also throughout specific questionnaires filled in by farmers. Particularly, for the sunflower oil production the research activity has concerned Northern and Central Italy, whilst for the olive oil data average values calculated in different areas of Tuscany have been used. Concerning sunflower oil production, due to large variability of the agricultural data, some few representative scenarios have been selected, as reported in Table 1. Particularly, different scenarios describe different hypothesis concerning yield and inputs. Therefore, the LCA implementation has included these five agricultural scenarios until sunflower seeds production and a standardized extraction phase as defined in the Table 2.

Table 1: Scenarios used to model the sunflower seeds production in the LCA.

Scenarios		**A**	**B**	**C**	**D**	**E**
Yield	t ha^{-1}	1.5	1.5	2.5	2.5	2
N	kg ha^{-1}	150	50	50	150	100
P (P_2O_5)	kg ha^{-1}	120	30	30	120	75
K (K_2O)	kg ha^{-1}	100	20	20	100	60
Herbicides	kg ha^{-1}	2.5	1	1	2.5	1.8
Fuel	kg ha^{-1}	390	180	180	390	285

Table 2: Data collected for sunflower oil production (extraction phase).

Data		**Seeds Cleaning and Drying**	**Decentralied Pressing Plant**
Distance transport	km	50	-
Duration of usage	h yr^{-1}	400	4000
Lifetime	yr	10	10
Energy input	kWh kWh^{-1}	0.0001	0.0268
Power output	kW	5800	300
Wastes/By-products	kg kWh^{-1}	0.0003	0.2264

For the olive oil production, three different scenarios have been considered. The first one describes a production chain where the husk is not reused and in some cases (i.e. small sized consortium plants) because of the difficulties to sell to other agro-industries, is disposed as waste. The second one illustrates a chain which allows the reuse of the husk as a fertiliser in the olive-grove. The third one permits the use of the husk for energy recovery. Input data used in the different scenarios are reported in Tables 3 and 4.

3. LCA results for the selected production chains

In this work, only CO_2 equivalent and primary energy consumption have been calculated for the vegetable oils production. Results obtained for sunflower and olive oil production chains are reported in the figures below.

Table 3: Scenarios used to model the olives production in the LCA.

Scenarios		**1**	**2**	**3**
Yield	kg $plant^{-1}$ yr^{-1}	28	28	28
N	g kg $_{olives}^{-1}$	5.14	0.00	5.14
P (P_2O_5)	g kg $_{olives}^{-1}$	2.75	2.50	2.75
K (K_2O)	g kg $_{olives}^{-1}$	9.11	0.00	9.11
Ca	g kg $_{olives}^{-1}$	6.14	3.29	6.14
Herbicides	g kg $_{olives}^{-1}$	0.00	0.00	0.00
Fuel	kWh kg $_{olives}^{-1}$	0.44	0.44	0.44

Table 4: Data collected for olive oil production (extraction phase).

Data		**Milling Plant**
Duration of usage	h yr^{-1}	1200
Lifetime	yr	10
Oil/Olives	%	15
Output (olive oil)	t $h-^{1}$	0.5
Electricity consumption	kWh kg $_{oil}^{-1}$	0.03
Water consumption	kg kg^{-1}	0.1
Material construction: steel	kg t^{-1} h	3900

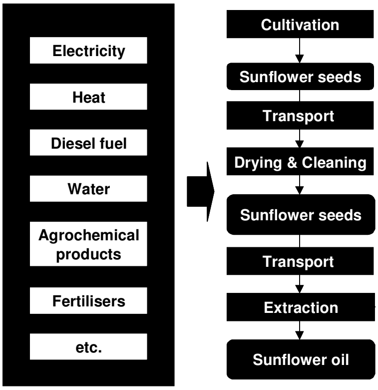

Figure 1: Modelization of the production chain for the sunflower oil.

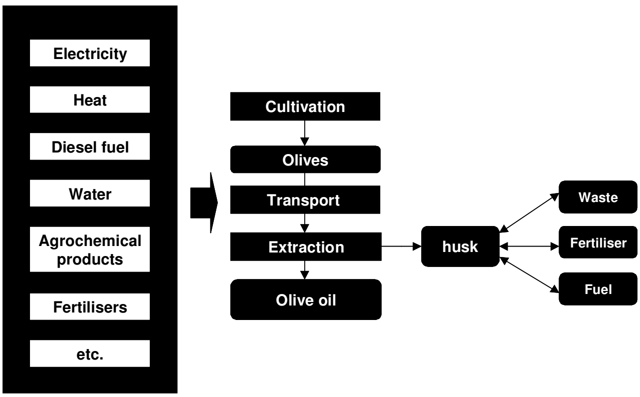

Figure 2: Modelization of the production chain for the olive oil.

4. Discussion and conclusions

Analysing the results obtained for the vegetable oils production, it is possible to develop some considerations. The CO_2 equivalent emissions are mainly determined by the agricultural phase (more than 90% for the sunflower oil and more than 70% for the olive oil). The primary energy consumption calculated for the different scenarios of the sunflower oil production shows a low variability. Concerning the olive oil production the reuse of the husk as biofuel allows to obtain lower CO_2 equivalent emissions and primary energy consumptions.

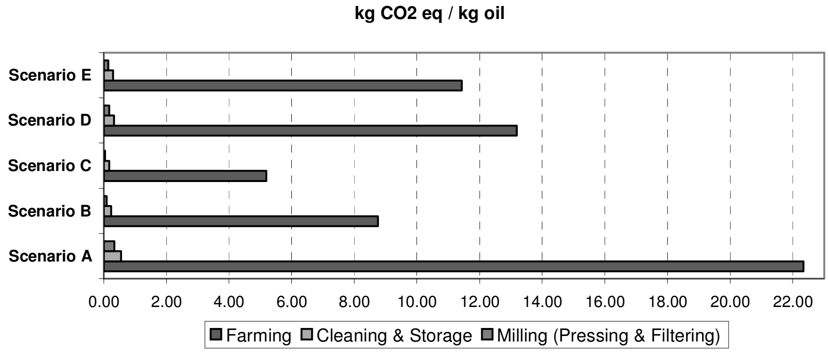

Figure 3: CO_2 equivalent emissions for the sunflower oil production.

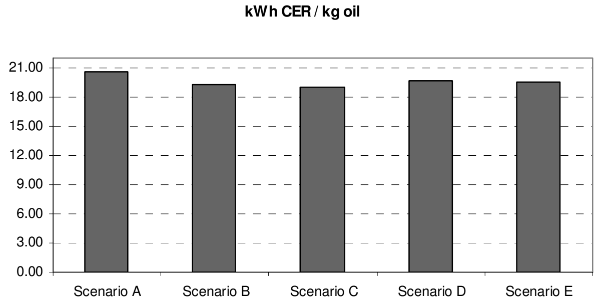

Figure 4: CER (Cumulated Energy Requirement) for the sunflower oil production.

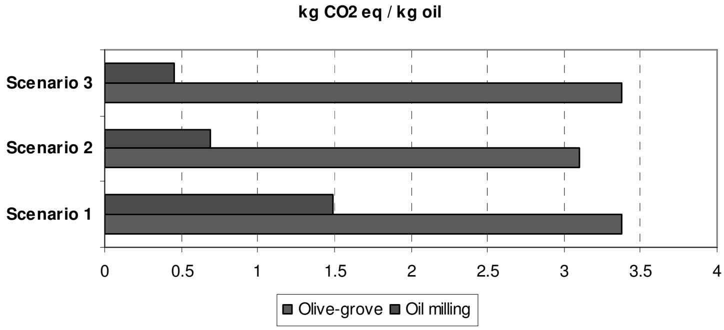

Figure 5: CO_2 equivalent emissions for the olive oil production.

Taking into account the obtained results, data with lower variability are needed for the cultivation phase in order to determine the impacts with higher precision. In fact, also considering a limited geographical area, a significant variability of the results has been detected. The reason for the high variability of the results is the fact that in Italian agriculture a fertilisation regime not adapted to the nutrient level in the soil is typical practice. This often leads not only to excessively high greenhouse gas emissions, but also to an increased acidification, eutrophication, a decreased soil quality, biodiversity and other factors which could not be investigated in this study. A more sustainable, adapted form of fertilisation in agriculture is thus prerequisite for the development of some environmental certifications for the agricultural products.

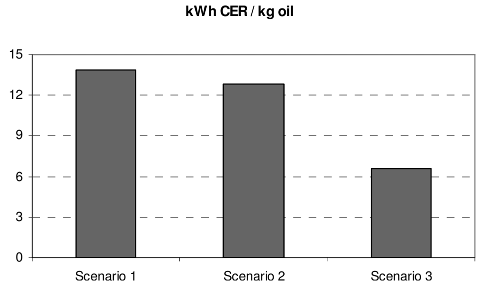

Figure 6: CER (Cumulated Energy Requirement) for the olive oil production.

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Italian experiences in Life Cycle Assessment of olive oil: a survey and critical review

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ABSTRACT

The aim of this paper is to present a survey and critical review of Italian studies concerning Life Cycle Assessment (LCA) applications in companies producing olive oil. The surveyed studies are based on the results of the latest National mapping produced by the Subgroup "Oils" in the Working Group on "Food and Agro-industry" in the Italian LCA Network. The Italian LCA studies of olive oil have developed over ten years; the first Italian studies date back to 2000, and since then, their number has progressively increased. In this paper a comparative analysis of the surveyed studies is used to perform a critical review to highlight common features and/or differences of the fundamental aspects of Italian LCA studies. The critical review, furthermore, enables us to identify application problems and critical areas and related methodological solutions and outline the "best practices" for the sector.

Keywords: Life Cycle Assessment, Olive oil, Italy, State-of-the-art, Italian LCA Network,

1. Introduction

The importance of the Life Cycle Assessment methodology (LCA) in the agro-food sector has been proved at the international, European and national levels. Among these, the decision to set up a specific Working Group (WG) focused on the agro-food and agro-industrial sectors within the Italian LCA Network (network for the exchanging of information, methodologies and best practices on the state of the art and perspectives of LCA in Italy) is mentioned. This WG is divided into subgroups dedicated to important Italian food products; one of these is the olive oil. The first important step to understand the issues involved in the application of LCA in the olive oil chain is to compare Italian LCA studies to provide a detailed picture of the characteristics of the LCA applied to the olive oil industry and useful information to define the best practices for this sector. The Italian experience in LCA studies of olive oil has developed over ten years; the first Italian studies, in fact, date back to 2000 and since then, their number has progressively increased to address various aspects of the olive oil chain: standard LCA studies, comparative analysis of different practices for the agricultural production of olives and their processing into olive oil, specific analysis of various waste treatment and analysis integrated with other methodologies (e.g. Life Cycle Costing - LCC). In this context, the aim of this paper is to present a survey and critical review of Italian studies concerning LCA applications in companies that produce olive oil. The surveyed studies are based on the results of the latest national mapping drawn up by the Subgroup "Oils" in the WG on "Food and Agro-industry" in the Italian LCA Network, and this analysis is an update of an initial study published in 2008 (Salomone, 2008). In particular, comparative analysis of the surveyed studies is used to perform a critical review to highlight any common features and/or differences connected to the selection of functional units, system boundaries, data sources and data quality, allocation procedures and impact categories. Furthermore, the critical review enables us to identify application problems and critical areas and their related methodological solutions to outline the best practices for the sector.

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2. Methodological approach

The approach of this study can be divided into three basic stages: 1. mapping the LCA Italian studies about olive oil, 2. collecting data regarding the application and methodological aspects related to the studies, and 3. implementing a comparative critical analysis. The first phase of the study maps Italian studies concerning LCA application in companies that produce olive oil (as of 31/12/2009 in Italy, 23 studies had been published about olives, olive oil and waste in the olive oil industry). After updating the mapping, all data relevant for the comparative analysis were collected for each study following the structure of the requirements of the ISO 14044:2006 (ISO, 2006) and using a dual input channel of the information flow: a checklist to collect the most important information of the study and a questionnaire to highlight the main issues that are not evident in the paper. In particular, the checklist was used to verify the content of the papers collected, as indicated in the requirements of the ISO 14044. However, it should be noted that the different types of publications of the papers cited in the mapping (reports in national and international conferences, journal articles, thesis of degree and Master) may influence the outcome of the study. It is possible, for example, that the author has been obliged to omit important information about the LCA study in a publication on a conference proceedings to respect a maximum number of pages; thus, it is impossible to collect this information for this analysis from a simple reading of the paper published. As a result, only data published in the papers were collected, and when the paper did not include objective information, these were noted as absent or, where possible, identified with the questionnaire. The questionnaire, in fact, was completed by the author of each study and was used to catch the information flow that was not been directly deducible from the published work, but that is essential to understand the most important application and methodological aspects of an LCA study. The collected data were then organised into a database to simplify the comparative and critical analysis and to highlight common features and differences of the fundamental aspects of Italian LCA studies.

3. Results and discussion

The 23 Italian studies analysed show highly heterogeneous characteristics in terms of size, content and object of analysis; they report results, more or less exhaustively, of olives, olive oils and waste from the olive oil industry. The form of publication and the methodology used show more homogeneous features: 96% are applied studies published in conference proceedings (international 39% and national 22%) and national magazines (17%), while the remainder (22%) are theses or other types of documentation. The LCA was the methodology of analysis used in 73% of the studies, LCA and LCC was used for 14% of the studies, and the other 14% include an LCA supplemented by an economic assessment.

Goal and scope definition – The goal and scope of an LCA should be clearly defined and consistent with its application; in general, problems concerning this stage of the study are related to defining the functional unit (especially for comparative studies), identifying system boundaries and defining the time horizon of the study. As shown in Figure 1, most of the papers surveyed evaluated potential environmental impact (91%), identified environmental burdens (82%), identified hot spots (73%) and checked the availability of data (50%) (each study may have had more than one goal).

Functional unit – Figure 2 shows the functional units adopted in the studies surveyed. When selecting the functional unit for the olive oil chain, it should be noted, however, that it is necessary to pay particular attention to the diction: the oils obtained by pressing olives are divided into *extra-virgin olive oil*, *virgin olive oil* and *current virgin olive oil* (*lampante virgin olive oil* also exists but is not a food), while the diction *olive oil* is used for a blend of refined oils and virgin oils (excluding the lampante virgin oil). Therefore, choosing 1 L of virgin olive oil as the functional unit is not equivalent to choosing 1 L of olive oil. Analysis of the studies revealed the difficulty in comparing oils with completely different organoleptic characteristics and yields (which also depend on cultivars, harvesting and oil extraction). This difficulty was observed in 18% of the cases; the solution was always the simplification: the functional unit was chosen to be a certain amount of generic oil or olive oil in order to include olive oils with different organoleptic properties. Another difficulty when choosing the functional unit was identifying a common element when considering the whole production chain, including olive oil waste treatment. In this case, a certain amount of olives was chosen as a functional unit. The choice of the functional unit, however, was strongly related to the purpose of the study and to the system boundaries.

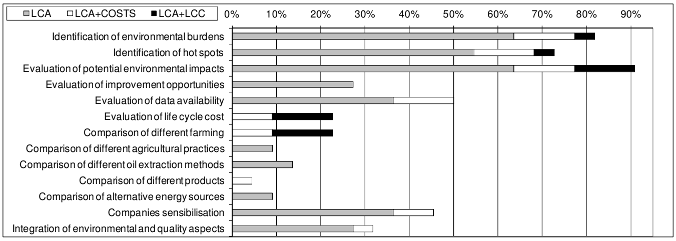

Figure 1: Goal and scope

System boundaries – When choosing the system boundaries, the surveyed studies adopted different methods; thus, general conclusions cannot be drawn from the results of the various studies but common issues can be identified. Indeed, the main problems encountered by the authors concerning the definition of system boundaries were determined by the lack of significant data about some processes of the chain (e.g., combustion of olive husk and pits, characteristics of the quality of compost and different types of husk, waste processing, end-life of the olive groves), which causes these processes to be excluded from the system boundaries. In other cases, doubts of the attribution of some treatment processes of olive oil waste were detected, such as the processes in the oil-husk industry. These problems were solved using several methods: exclusion from the system, inclusion in the system and appropriate allocation among the various products of the oil-husk industry and/or appropriate choice of the functional unit (e.g., quantity of olives processed). Despite these differences, however, it was possible to verify, as shown in Figure 3, the chain phases that have received the most attention: cultivation, oil production, husk treatment and transport linked to these processes.

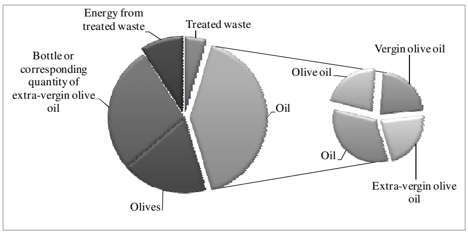

Figure 2: Functional unit

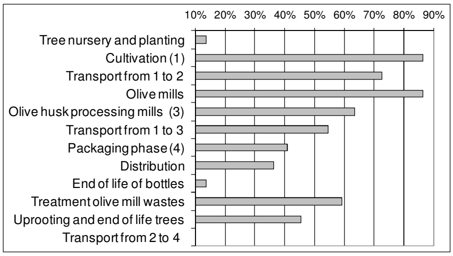

Figure 3: System boundaries

Of the applied studies, 64% specified exclusion of some processes from the system boundaries because of missing data and/or incomplete information (in 79% of cases). While the system boundaries and exclusions were not clearly detailed in all studies, the analysis revealed that: 10% of the studies analysed systems with organic cultivation, 53% analysed systems with conventional cultivation, 16% of the studies that included the agricultural phase in the system boundaries also accounted for olive grove planting, 37% compared two or three farming systems (conventional, integrated and organic), as shown in Figure 4. The cultivation systems were also differentiated according to the agronomic technique (dry or irrigated). The analysis also revealed that: 58% of studies that included olive oil production analysed the three-phase continuous system, 32% analysed the two-phase continuous system, 26% analysed the discontinuous system and 11% investigated the de-stoning process. 77% of the studies specified geographical boundaries, whereas only 55% specified the temporal boundaries (the studies that specified temporal boundaries also specified geographical ones). 59% of the studies were comparative, as shown in Figure 5. 64% of the applied studies used some form of allocation: in these analyses, 79% used allocation methods for olive oil and for husk; 21% for the various products of the oil-husk industry; and 7% for sunflower oil and meal. In these studies, the allocation was calculated in 36% of the cases based on the price, in 14% of cases by mass, in 21% of cases by price and mass and the remainder did not mention the allocation method.

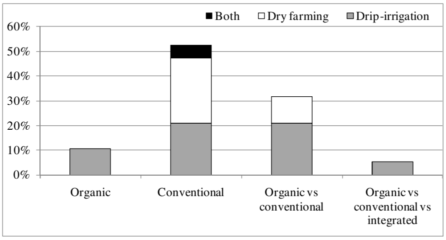

Figure 4: Farming characteristics

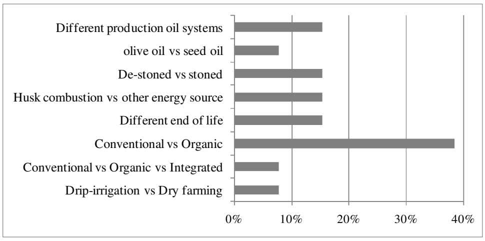

Figure 5: Comparative studies

Data quality - 91% of the analysed papers used primary data collected from various companies of the olive oil sector, 100% used the LCA database and 36% used data available in the literature. In 45% of the studies, the data quality was verified through sensitivity analysis. The most used databases were Buwal 250 (59%), Ecoinvent (45%), ETH-ESU 96 and IVAM LCA 3 (both cited in 41% of studies).

Life Cycle Inventory analysis (LCI) – The inventory phase of the agro-industrial sector still suffers from a lack of data availability and data uncertainty (especially for certain types of materials, such as herbicides and pesticides), problems related to emissions estimates of nitrogen and phosphate compounds and dispersion of pesticides, the use of agricultural machinery and the balance CO_2 emissions.

The comparative analysis conducted on the Italian studies of LCA, considering only the applied studies including the agricultural phase, confirmed these critical issues:

- 74% of the authors of these studies lamented the lack of data about the production of pesticides in databases; 14% of these excluded the process from the system boundaries and 86% of the studies used data in the database for similar compounds and weighted the results based on the active ingredient.
- 53% of the authors lamented the lack of data on fertilisers production in the databases and their solution was always to use the data in the database modified according to the content of N, P and K.
- 11% of the authors lamented the lack of data concerning the production of herbicides in databases and the lack of data regarding emissions from herbicides; their solution was always to exclude them from the system boundaries.
- 68% of the authors of these studies lamented the lack of data regarding emissions due to pesticide use and the difficulty to calculate the pesticide dispersion in soil, air and water; their solution was to use models to estimate emissions in 23% of the studies (such as: Mackay et al., 1992; Hauschild, 2000; Birkved et al., 2006), in 62% of the cases the emissions were estimated using data in the literature or were considered to be similar to other compounds and in 15% of the cases they were excluded.
- 58% of the authors lamented the lack of data regarding emissions from fertiliser use and the difficulty to calculate the dispersion in soil, air and water; the solution in 27% of the cases was to use estimation models, such as Bentrup model (2000) for nitrogen compounds, and data from literature for the behaviour of phosphorus and potassium fertilisers; in 73% of the cases the substances contained in the fertiliser were calculated using the ratio between real weight and molecular weight and then estimating emissions to the air, water and soil.
- 47% of the authors had problems calculating emissions from the use of agricultural machinery based on the type of work, due to insufficient data or uncertain data sources; the solution was always to consider the emissions to be derived from fuel consumption.

Other issues encountered in these studies are connected to allocation, balance of CO_2 emissions and lack of some characterisation methods. Allocation, especially in systems where the various waste treatment technologies are included, was considered a problem in the 36% of the studies. In these cases, the most common solution (75% of the cases) was to include the process with full allocation to the main product and calculation of the advantage obtained from the *avoided product*, whereas allocation was applied in 25% of the cases. The balance of CO_2 emissions was difficult to determine for the 41% of the authors due to a lack of specific data, and the solution was to use generic data collected from the database, if available. Lack of characterisation methods for pesticides (50%), land use (14%) and water use (9%) were also problems; in the case of pesticides, the problem was solved by assuming similar characterisation factors to known quantities or by using analogous evaluation methods; and in case of land use and water use, the processes were excluded.

Life Cycle Impact Assessment (LCIA) - Regarding the impact assessment, only 14% of the studies reported all phases of LCIA, while 86% reported only a partial assessment: classification and characterisation in 95% of the cases, normalisation in 59% of the cases, grouping-evaluation in 14% of the cases and weighting-evaluation in 68% of the cases. Continuing the comparative analysis, identifying the selected impact categories and related assessment methods was particularly complex because some papers lacked sufficient elements to be able to detect the full data. Despite these difficulties, however, it was possible to achieve the results shown in Figure 6. The most used evaluation method was the CML 2000 (55%), followed by Eco-Indicator 99 (50%), EPS 2000 (36%) and EDIP 96 (14%). Often, the CML was applied with modifications and/or additions, such as updates of the characterisation factors (IPCC for GWP), the addition of the Land Use, the Energy Content or weight factors that take into account economic aspects. On the contrary, the changes to the method Eco-Indicator 99 (particularly the E/E) mainly described the costs and benefits of olive oil on human health. The most commonly used impact categories were Global warming, Ozone layer depletion, Acidification, Photochemical oxidation and Human Toxicity.

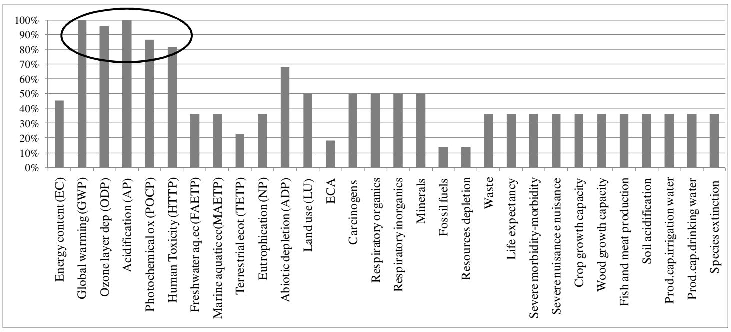

Figure 6: Impact categories

Life Cycle interpretation – All reviewed studies reported information on the interpretation phase, though they had different levels of depth. In all of these, it was possible to identify the significant issues, but the papers that reported conclusions, recommendations and limitations are few. Moreover, the reported elements are too fragmented and poorly defined to allow us to achieve important comparative results. Different choices of functional units and system boundaries did not allow us to reach unequivocal conclusions. However, we can certainly say that of the 17 studies that accounted for both the agricultural and industrial phases (with or without the intermediate stage of transport), all of them identified the agriculture phase as the most pollutant and the agricultural phase was confirmed to be the most pollutant also in the analysis with other stages of the life cycle (cultivation and production of olive oil), except for one case that identified the distribution phase as the most pollutant. For the agricultural phase, the agronomic practices with the greatest environmental impact were the spreading and use of fertilisers, the spraying and use of pesticides and the spreading and use of olive oil wastewater. The most important impact categories were eutrophication, acidification and ecotoxicity (in its various forms) and the most pollutant substances were fertilisers (55%), pesticides such as dimethoate, Carbaryl, Fenthion and unspecified (27%), vegetable water (23%) and energy consumption (18%). 41% of the analyses used sensitivity analysis.

Critical review CR- The CR of the experts is a process that seeks to ensure that the LCA study is aligned with the requirements of ISO 14044:2006, is scientifically and technically valid, is consistent with the goal and scope of the study, and is transparent and consistent. None of the examined studies presents elements that suggest that a critical review was carried out by external independent experts.

4. Conclusions

The comparative analysis of LCA studies on olive oil is an essential step for understanding the methodological and application issues specific to these food-chain. This is also an indispensable source of information for the definition of the best practices of the sector; however, further investigation is required. A sample set of best practices can, however, be identified based on the choice of functional unit, as shown in Table 1.

The critical comparative analysis revealed interesting points of reflection. The processes identified as those with greater environmental impact are also those with the least data, such as the production and use of pesticides, herbicides and fertilisers; therefore, uncertainties and variability remain in the data. The definition of the best practices of the sector is the priority for the improvement and expansion of databases for these substances; however, the models that estimate their dispersion in water, air and soil must also be simplified. The olive oil chain should not be understood as simple olive processing and olive oil production, followed by the problem of disposal and waste management. The whole olive oil chain must include the systems, treatment plants and waste recovery to obtain biomass for energy use, to produce compost and other substances that are useful to the cosmetic and pharmaceutical industries. Thus, this sector is multi-product and each option must be properly assessed considering the whole chain from both environmental and economic points of view.

Table 1: Best practices for conducting LCA of olive oil – example for the functional unit

Requirement	Possible choices	Recommended when
Functional unit	olives	system boundaries include all the phases from cultivation to waste treatment
	oil	in a comparative study of olive oil and other seed oil
	olive oil	in a comparative study of olive oils with very different organoleptic characteristics
	extra-virgin olive oil virgin olive oil	in a single product study or in a comparative study of olive oils with very similar organoleptic characteristics
	olive mill waste	if the system boundaries include only waste treatment processes

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Economic, agronomic and environmental integrated analysis of Durum wheat cultivation cropping systems

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ABSTRACT

Since it has been widely demonstrated that farming is one of the phases that most contributes to pasta and bakery environmental impact, Barilla has promoted a specific project with the aim of analysing and comparing different cropping systems for the cultivation of *Durum wheat*. Several Mediterranean four-year crop rotation including also Durum wheat, have been investigated from a life cycle perspective; the system analyzed are typical of different Italian regions. The system boundaries includes different important elements, such as: crop rotation, tillage activities, crop yields, fertilizers, herbicides and pesticides use, including relative emission to air and water. Life Cycle Assessment methodology was applied to analyse the cropping systems environmental impacts using Carbon Footprint, Water Footprint and Ecological Footprint as indicators. The results obtained were, finally, integrated with specific economic and agronomic indicators, in order to provide guidance on the "sustainability" and the “feasibility” of the cropping systems analysed.

Keywords: durum wheat, fertilizers, crop management

1. Introduction

In recent years Barilla has undertaken many studies aimed at quantifying and reducing its environmental impact. Many literature studies can prove that one of the main impacts of the Food Industry is the agricultural stage. For this, Barilla has decided to promote specific projects for the implementation of more sustainable cropping systems for the production of the most important raw material used in their production: the Durum wheat. The term “sustainability” is properly used in this case, because the analysis is based on a holistic approach, taking into consideration Economic, Agronomic, Safety and Environmental indicators.

2. Goal and scope

The project is mainly focused on identifying feasible alternative cropping systems as an alternative to the most diffused in Italy for the cultivation of Durum wheat, while maintaining high quality and health standards of the products. This scope is pursued by analyzing and evaluating the characteristics of cropping systems identified, from an agronomic, economic and environmental perspective, with relation to medium/long-term production periods.

Finally, analysis outcome should constitute a basis in the integration of crop guidelines adopted by Barilla, in order to promote activities aimed at developing a more sustainable way of cultivating Durum wheat.

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3. System description

System boundaries (Figure 1) includes all the agricultural activities, from the fertilizers production and spreading, the soil preparation and plants protection, to the harvesting and storage of the product; emissions to air and water from fertilizers use has also been considered. An economic analysis was further conducted by using the Net Income indicator[1].

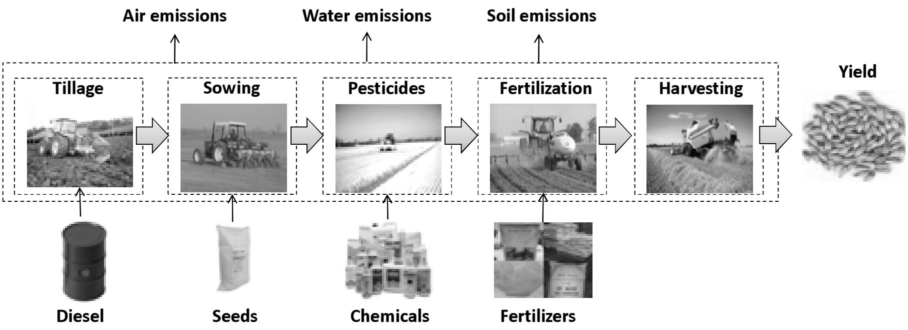

Figure 1 – System boundaries considered for the study

4. Methods

The Durum wheat cultivation was analyzed by identifying different cropping systems, representatives three main geographical Italian areas: Northern Italy, Central Italy, Southern Italy[2]. The standard cropping system is a four-year rotation in which the cultivation of different crops, other than Durum wheat, is planned.

The assessment tool used as methodology of LCA is governed by international standards ISO 14040 series, according to the steps listed below:

- Definition of aims and objectives: defining the objectives, the functional unit of reference and the boundaries of the system analyzed;
- Inventory: a study of the process life cycle and reconstruction of the energy flows and materials needed for the operation of the system analyzed.
- Analysis of impacts: highlight the extent of the changes generated as a result of emission into the environment and consumption of resources calculated in the inventory.
- Interpretation and Improvement: a comparison among the results obtained for different crop rotation was drawn only within each specific area considered.

The functional units chosen for the study are both 1 ton of Durum wheat and 1 cultivated hectare for the crop rotation period, including, therefore, also the impacts due to the other cultivation. SimaPro 7.1.8 was used to assess the cropping systems environmental impacts.

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[1] See "economic indicators" for more detailed information

[2] Two possible cultivation scenarios were investigated for each cropping system, differed by agricultural operations:

- *High Input (Hi) scenario*: hard soil cultivation, high fertilizer use and, if needed, irrigation activities;
- *Low Input (Li) scenario:* minimum tillage activities and fertilizer use and no irrigation *(except for tomatoes)*.

4.1 Influence factors

As the following list explains, many factors can influence the different environmental and agronomic impacts related to a cropping systems:

- The "in field activities" imply the use of different machinery and timeframes, resulting in a variable quantity of diesel used.
- The kind and quantities of fertilizers used vary on the basis of tillage operations, crop species, choice of a Hi/Li system, geographical location and soil properties.
  The use of five chemical fertilizers was considered: Ammonium Nitrate, Urea, Triple Superphosphate, Diammonium Phosphate, NPK. Emissions to air and water (e.g.: N_2O, NH_3 etc.) due to fertilizers spreading were accounted (Sequi, 1989; Brye *et al.*, 2001; Benedusi, 2006).
- The pesticides and herbicides production and use was considered.
- The crop yields within each specific cropping system, not only depends on all the above-mentioned factors, but also on the regional weather and climatic conditions (not considered within this study), as Figure 2 demonstrates.

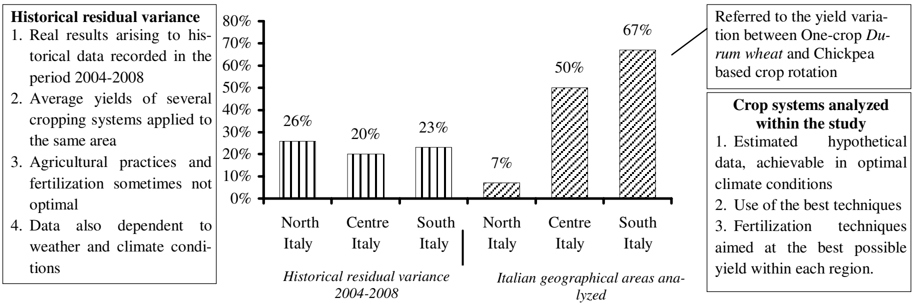

Figure 2: Comparison between the fluctuations in Italian Durum wheat cultivation average yields (2004-2008) and those related to the different cropping systems analyzed

4.2 Performance indicators

The parameters used to quantify the different cropping system impacts are divided into:

<u>Environmental indicators</u>

1. *Carbon footprint*: also known as "global warming potential" (GWP), expresses the total amount of greenhouse gases (GHG) produced to the system and is usually expressed in equivalent tons of CO_2.
2. *Water footprint*: it measures the water consumption of a system in terms of water volumes polluted or consumed because of the processes, irrigation, evaporation by plants.
3. *Ecological footprint*: is a measure of how much biologically productive land and water an activity requires to produce all the resources it consumes and to absorb the waste it generates. It is measured in global hectares (gha).

<u>Agronomic indicators</u>

4. *Nitrogen Index*: measurement of nitrogen availability determined by the previous crop residue, the contribution of chemical fertilizers and the time required to biologically degrade the organic substance of the preceding crop;
5. *DON Index*: this index expresses the cultivation safety aspects related to the possibility of reducing pathology occurrence linked to the deoxynivalenol mycotoxin (DON).

Economic indicators

6. *Net Income*: represented by the direct costs of cultivation (in field activities + technical tools), the gross marketable production (gps), updated to the price lists at November 17, 2009, and the gross income (gi); i.e.: the difference between direct costs of cultivation and gps[3].

5. Results

A list of the main outcomes of the analysis is following provided for each indicator:

1. *Carbon footprint*: fertilizers and agricultural operations lead a high contribution to total GHG emissions due, in general, to *durum wheat* and other cultivations crop.
   Low input systems always produce lower GHG emissions than High input ones, because of a lower quantity of fertilizer used and lighter soil preparation (Figure 3).
2. *Water footprint*: results show that water footprint referred to 1 cultivated ha is not a significant parameter for the comparison between cropping systems because more than 90% of the impacts are due to so-called “green water”, that is not strictly related to the cultivation system applied. The water footprint of 1 t of *Durum wheat* is, then, strictly dependent on specific crop yield.
3. *Ecological footprint*: the ecological footprint of 1 cultivated ha depends on the cropland and is, then, not a significant parameter for comparative purposes. The impacts related to 1 t of *Durum wheat* depend essentially on the yield.
4. *Nitrogen Indicator*: results confirm that the cultivation of legumes the year before durum wheat, determines high nitrogen availability and, consequently, lower environmental impacts due to a minor need for chemical fertilizers (Nemecek *et al*, 2006)
5. *DON Index*: the latitude is a fundamental factor in determining outcrop pathologies; for this reasons the southern regions have a natural low frequency of this kind of problems, while, in the northern ones, crop diversified systems are generally favoured over the single-crop cereal-based systems.
6. *Net Income:* the true income of a system strictly depends on the current food prices as well as the costs of agricultural operations, materials (fertilizers, etc.) and labour: for this reason, higher is the yield, higher is the farmers’ net income. Generally it can be stated that more differentiated crop system yield, higher profit for the farmer (Figure 3).

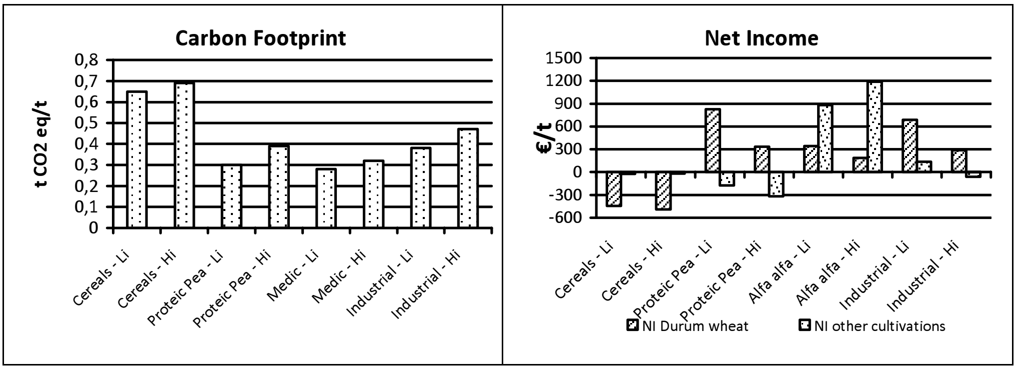

Figure 3: Carbon footprint and Net income results example for Centre Italy crops systems

[3] “gps” do not considers agricultural coupled and uncoupled aid.

Given the non comparability of the different performance indicators used and considering the complexity of results interpretation, an aggregated "scoring point system" was built in order to identify which are the more sustainable among the crop systems considered in the study: the environmental results obtained from the LCA were combined with the agronomic and economic analysis, expressing the total efficiency of the different crop systems analysed. The scores were assigned as following explained:

- for each performance indicator, the maximum and minimum values, related to the crop systems considered within each area, were identified;
- the difference between the two values was divided into five identical ranges;
- a progressive score, from 1 to 5 points, was assigned to each of the ranges, where: 1 represents the worst result and 5 the best;
- the indicators obtained were finally tallied for each crop system obtaining a total score.

Since the "Net Income" indicator could also express situations of economic loss, also a negative scale (from -1 to -5) was integrated.

This must however be merely considered a qualitative comparison, because different parameters, otherwise not directly comparable, are combined together.

A comparison among the outcomes related to the different crop systems was made within each specific area (i.e. Northern, Centre and Southern Italy): the more sustainable crop rotations so identified are examined in the following paragraph 5.1.

An example of the results obtained by applying the scoring point system described to the case study of Centre Italy are shown in Figure 4.

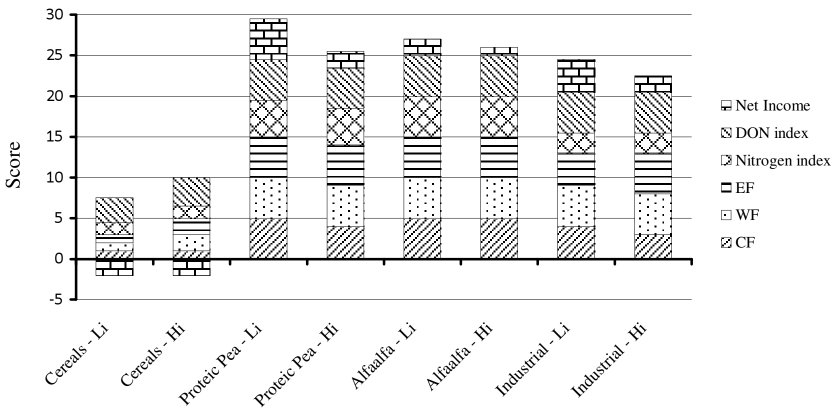

Figure 4: Sustainability comparison applied to the Centre Italy cultivations: the more sustainable scenario is the "Proteic Pea – Low input" cropping system.

5.1 Possible improvement strategies

Considering the results obtained by comparing the crop rotations using the methodology previously explained, an estimation of the predictable improvements achievable by applying the more sustainable and feasible cropping systems, compared to a simplified current real framework, was made in terms of: carbon footprint reduction, net income increase, farmland saving referred to Barilla's Durum wheat need from the specific region[4] (Table 1).

[4] 26% comes from North Italy, 38% from Center Italy, 15% from south Italy and the remaining 21% from France, USA, Canada, Mexico, Turkey, Spain, Greece, Australia (Data 2008)

Table 1: Main improvements achievable with the application of the most sustainable and feasible cropping systems compared to a simplified current real framework for each area

AREA (Barilla's 2008 supply)	Current most diffused situation	Most sustainable and feasible alternative cropping system	Predictable improvements			
			Indicator	UF	Referred to 1 t of Durum Wheat	Referred to a 4 year rotation on 1 ha
North Italy (26%)	Industrial (Hi) (Soy, Durum wheat, Maize, Wheat)	Diversified (Li) (Soy, Durum wheat, Rapeseed, Maize)	Carbon Footprint	kg $CO_{2\ eq}$	-90	-3,570
			Net Income	€	28	1.420
			Farmland	ha	0	na
Centre Italy (38%)	Cereals (Hi) (3 years of Durum wheat, Sorghum)	Proteic (Li) (Proteic Pea, Durum wheat)	Carbon Footprint	kg $CO_{2\ eq}$	-390	-3,670
			Net Income	€	116	1.120
			Farmland	ha	0	Na
South Italy (15%)	One-crop (Durum wheat)	Fodder (Li) (Oats and Vetch, Durum wheat)	Carbon Footprint	kg $CO_{2\ eq}$	-270	-3,770
			Net Income	€	107	1.110
			Farmland	na	-0,1	na

6. Conclusions

The aggregated analysis conducted integrating LCA methodology, agronomic knowledge and economic aspects led to identify the Durum wheat crop systems that are more sustainable compared to the currently most diffused scenarios. The qualitative results could be taken into consideration for the next updating of the crop guidelines suggested by Barilla; as these indications should be tested and confirmed through in-field experimentations.

Taking a closer look at the study results, it is important to highlight that the possible improvements over the current situation in Northern Italy are not significant, and investments for this area are not justified; in Centre Italy expected improvements over the most diffused cropping methods can be really significant, while in Southern Italy possible improvements could produce environmental and economic benefit, but, currently, Barilla purchases only 15% of Durum wheat from this area.

Lastly, the study demonstrates that the "sustainability" is a feasible concept also for agricultural sector: the best Durum wheat crop systems identified demonstrate that agronomic and environmental improvements can bring also an higher farmer's net income. Pursuit of sustainability can lead to improvements of economic, social and environmental issues.

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The preliminary LCA of membrane processes for olive oil wastewater polyphenols recovery

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ABSTRACT

The aim of the study is to apply a preliminary Life Cycle Assessment to the new integrated technology for Olive Oil Wastewater (OOWW) treatment and polyphenols recovery from biphasic olive mill. Treatment and disposal of OOWW are serious environmental problems for the agricultural and olive oil sector due to the high pollution load of the organic compounds. The OOWW treatment process consists in the OOWW selective fractionation in five steps: the physico-chemical pre-treatment with enzymes and acidifying substances; the Microfiltration; the Ultrafiltration; the Nanofiltration and the Reverse Osmosis. Once removed toxic potential pollutant of OOWW components, the concentrated organic substances obtained from the tangential streams in each filtration step are of high economic value for novel food, fitoterapic or cosmetic industries. The benefits of this procedure are the following: it treats a sewage that otherwise it would be a waste (containing pollutants such as COD and BOD_5) and, at the same time, produces natural products with a potential economic value. In the present study, a preliminary way, the sensitivity analysis is carried out to compare the OOWW treatment with tangential flow membrane technology (Best Available Techniques) with a traditional wastewater treatment for removal COD pollutant.

Keywords: LCA, Membrane technologies, Polyphenols, Recovery, Olive oil wastewaters.

1. Introduction

The study attempts to solve the environmental problems of OOWW disposal and simultaneously to evaluate all the components of OOWW using selective separation based on tangential flow membrane technologies. Different filtration techniques are used to fractionate OOWW from biphasic olive mill in three principal streams consisting in: purified and enriched antioxidant polyphenols with low molecular weight (MW), pure vegetable water and a concentrate of organic substances without (or extremely impoverished) polyphenolic content (Russo, 2007). It is possible to use filtration membranes that operate on the principle of tangential filtration. Usually the filtration process consists of a fluid flowing perpendicularly through a filtration medium which separate the filtrate. When the filter is plugged, it is necessary to wash it or replace it (replace the filtration cartridges, etc.). In tangential filtration, on the other hand, the fluid to be filtered is separated, through a semi-permeable membrane, in two flows, the permeate and the concentrate flow. The permeate flow is the flow fraction which passes through the membrane. The concentrate is the flow fraction which, enriched in solutes or suspended solids, does not go through the membrane. The fluid flows inside the membrane at a very high speed, parallel to the surface of the membrane itself, keeping it constantly clean. The technology studied is an integrated system of all stages of filtration: Micro, Ultra, Nano and Reverse Osmosis.

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Microfiltration (MF) and Ultrafiltration (UF) are membrane filtration processes that work with low pressure. MF is used to separate colloids and suspended solids with dimensions smaller than one micron (µm). UF is normally used for the separation of organic compounds with a medium-high molecular weight. Nanofiltration (NF) and Reverse Osmosis (RO) are high pressure membrane processes which operate a total or partial demineralization of the filtered waters. The different filtration stages are characterized from different molecular weight cut-off (MWCO) and Filtration degree (measured in µm). The microfiltration stage is made by tubular ceramic membranes (Fig.1) in titanium oxide.

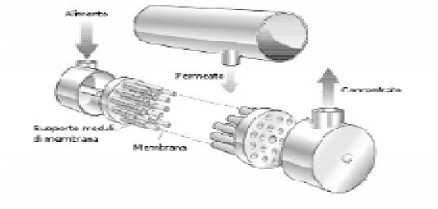

Figure 1: A typical system of membrane ceramic tubular (Pizzichini *et al*., 2009)

The UF, NF and RO stages are made by "spiral wound module" membranes in polyethersulfone (PES). This design tries to maximize surface area in a minimum amount of space. It is the less expensive but more sensitive to pollution due to its manufacturing process. It consists of consecutive layers of large membrane and support material in an envelope type design rolled up around a perforated steel tube (Fig.2).

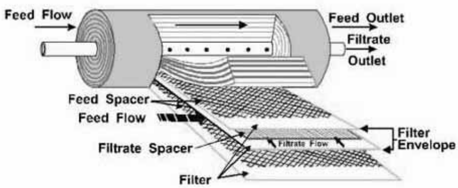

Figure 2: A typical system of "spiral wound module" membrane in PES (Sepra, 2010)

Coupling the MF and UF system with an NF and RO system allows to obtain dischargeable wastewaters according with the most severe regulations OOWW laws. The OOWW separated by membrane systems can be recycled many times reaching in some cases the so called zero discharge level.

2. Material and methods

As a preliminary step of the study, the Standard Life Cycle Assessment (LCA) methodology (ISO 14040:2006; ISO 14044: 2006) was used for the identification of the environmental impacts of the novel processing techniques. The study applies a LCA methodology at the new integrated technology for OOWW treatment and polyphenols recovery, from biphasic olive mill, with a membrane processes during a test period. The LCA is an objective evaluation procedure to examine the energetic and environmental impact related to a product, process or activity. The evaluation covers the whole life cycle of the product, process or activity and includes the extraction and treatment of raw materials, manufacturing, transport, re-use, recycling, and waste treatment. The environmental assessment of novel products and processes is important for "novel food" (REG.EC n.258/97) producers, since many of them have introduced sustainability as a core company goal, like in this case study. In the last years the novel system LCA, in particular related to food product and food processing, has become a great development field (Hospido *et al.*, 2010) (Notarnicola *et al.*, 2008). For Life Cycle Impact Assessment (LCIA) phase the Impact 2002+ method (Jolliet *et al.*, 2003) is applied. The Impact 2002+ method allows to calculate the mid- point categories and the end-point categories, it comprehends four damage categories: Human Health, measured in DALY (Disability Adjusted Life Year); Ecosystem Quality, measured in PDF*m^2*yr (Potentially Disappeared Fraction); Climate Change, measured in kg of CO_2 equivalent in air, that derives from impact category Global warming; Resources, measured in MJ; Non renewable energy and Mineral extraction.

3. Results and discussion

3.1 The goal and scope definition, System boundaries, Inventory

The aim of the LCA study is to calculate the environmental and energy impacts of OOWW system treatment using selective separations based on tangential flow membrane technologies for polyphenols recovery. The technology is an integrated system in which the OOWW from biphasic olive mill, is selective fractionated in five steps: the physico-chemical pre-treatment with enzymes pectinase and acidifying substances; the Microfiltration (MF); the Ultrafiltration (UF); the Nanofiltration (NF) and the Reverse Osmosis (RO). The main system characteristic is that it treats olive oil wastewater and, at the same time, produces the novel products exploiting the antioxidant properties of polyphenols as a semi-manufactured good for "novel food", fitoterapic and cosmetic industries. The plant is a patented technology PCT (n° EP 09425529) of the Phenofarm srl company (Scandriglia, Rieti, Italy). The plant occupies 300m^2 of land. The functional unit (FU) is 10 m^3 of OOWW per day. The systems operate 20 hours per day and the remaining four hours are used for washing. Since the system can treat different raw material inputs from agriculture, in the present study the plant operating time has been assumed equal to 8 hours per day with 1.6h of washing. The system boundaries are from OOWW storage to the obtainment of co-products (MF concentrate, UF concentrate, NF concentrate and RO concentrate). Allocation between different products and co-products are based on mass criteria. The time boundary was the pilot production test for the year 2009 and is equivalent to the three months of the milling olive oil season. Figure 3 represents the flow chart of the studied system.

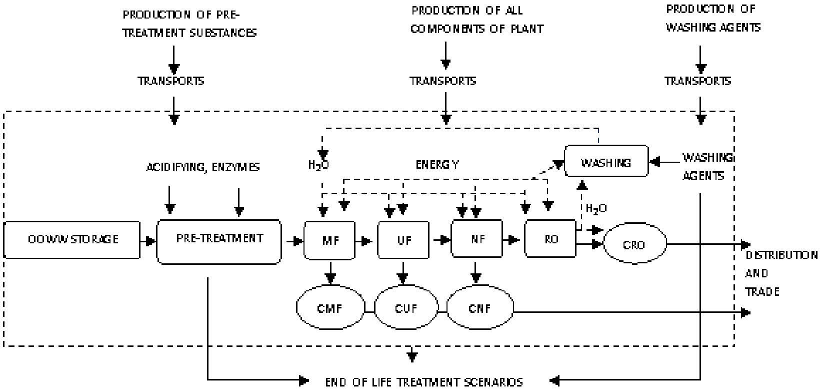

Figure 3: Flow chart of system studied

Each phase modeling includes the raw material extraction, the manufacturing material, the transport from suppliers, the end of life treatments and running costs such as energy, water etc., and investment costs. The quality data used were in the first step, the parameters on laboratory scale (pilot plant) and later, were the specific data on industrial scale. Since the gathering of inventory data was done during test production, when the system will work at full capacity a possible adjustment is foreseen. The LCA most used database has been Ecoinvent 1.2. (Frischknecht *et al.*, 2004.). The component technical life time expected varies accordingly to each component proper maintenance schedule and it has been estimated from a minimum of 5 year (e.g. for pumps) to a maximum of 20 years (e.g. stainless steel tanks).

3.2 Impact assessment

The impact assessment results show that the reverse osmosis phase (26%), the nanofiltration phase (24%), the pre-treatment phase (22%), which include the production of components plant, the transports from suppliers, use, and disposal sub-phases, have a major impact, due to their energy consumptions (Fig.4). The Resources (36%) and Climate Change (34%) are the damage categories most affected (Fig.5). In energy consumptions are included direct system consumptions from the use phase and energy consumptions incorporated in plant component materials. Table 1 describes the results of the characterization phase reported per impact categories.

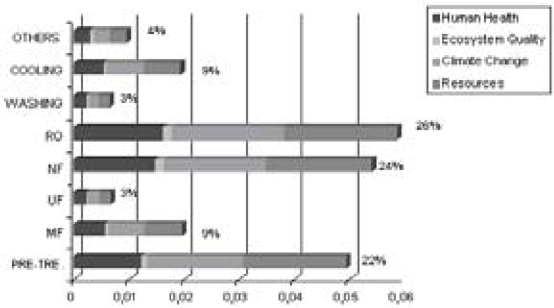

Figure 4: Processes contribution in LCIA weighting (%)

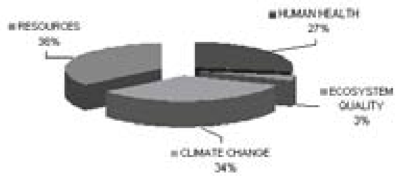

Figure 5: Damage categories contribution in LCIA weighting (%)

Table 1: Characterization results in LCIA (equivalent units) [FU: 10 m^3]

IMPACT CATEGORY	UNIT	TOTAL
CARCINOGENS	kg C_2H_3Cl	3.9
NON-CARCINOGENS	kg C_2H_3Cl	5.8
RESPIRATORY INORGANICS	kg PM2.5	0.57
IONIZING RADIATION	Bq C-14	14772
OZONE LAYER DEPLETION	kg CFC-11	7.6E-05
RESPIRATORY ORGANICS	kg ETHYLENE	0.16
AQUATIC ECOTOXICITY	kg TEG WATER	93284
TERRESTRIAL ECOTOXICITY	kg TEG SOIL	8923
TERRESTRIAL ACID/NUTRI	kg SO_2	12.58
LAND OCCUPATION	m^2ORG.ARABLE	2
AQUATIC ACIDIFICATION	kg SO_2	4.7
AQUATIC EUTROPHICATION	kg PO_4 P-LIM	0.03
GLOBAL WARMING	kg CO_2	754.8
NON-RENEWABLE ENERGY	MJ PRIMARY	12031.2
MINERAL EXTRACTION	MJ SURPLUS	27.44

The main results of the impact characterization phase are as follows: in the impact category *Carcinogens* the pre-treatment phase has the major impact due to the heat from natural gas; the most important substances emitted into air are the *hydrocarbons aromatic* for a weight of 0.9 kg of C_2H_3Cl eq.; for the *Respiratory inorganics* category the reverse osmosis phase has a major impact due to the electricity consumption; the main substances emitted into air are the *sulphur dioxides* for a weight of 0.27 kg of PM2.5 eq.; in *Ozone layer depletion* the reverse osmosis phase has a major impact due to the electricity consumption; the most significant substance emitted into air is *halon 1211* for a weight of 3.91E-5 kg of CFC-11 eq.; in *Terrestrial acidification and eutrophication* the reverse osmosis phase has again the major impact due to the electricity consumption, the main substances emitted into air are the *nitrogen oxides* for a weight of 8.78 kg of SO_2 eq.; the reverse osmosis phase is the also major cause of *Global warming* always due to high electricity consumption; the most important substance emitted into air is *carbon dioxide fossil* for a weight of 723 kg of CO_2 eq.; in *Non renewable energy* the reverse osmosis phase has a major impact due to electricity consumption, the main substances used are *gas natural in ground* and *oil crude in ground* for a weight of 5.42E3 of MJ primary and of 3.74E3 of MJ primary.

3.3 Sensitivity analysis

The Sensitivity analysis is a systematic procedure for estimating the effects of the choices made regarding methods and data on the outcome of a study (UNI EN ISO 14040:2006). In this work a preliminary comparative analysis of one treatment versus a traditional technology for waste water treatment is presented. However is important to point out that the new system not only treats OOWW but also produces semi-manufactured goods for "novel food" field. A comprehensive comparison which is out of the scope of the present work step should also include the comparison with traditional system for the production of these by-products. Since the main system characteristic is that it treats olive oil wastewater a first comparison with a "wastewater treatment for COD removal" of "LCA food" database has been performed. Traditionally, the olive oil wastewaters follow the usual chemical-biological treatment at specific waste disposers and don't follow the municipal wastewater treatment because they have high values of BOD_5 (Biological Oxygen Demand) and COD (Chemical Oxygen Demand). However, the "LCA food database" process, used for comparison, measures the energy consumption of a municipal waste water treatment plant in Denmark for the removing of COD pollutant (1.1 kWh of *Electricity, natural gas* for 1kg COD or BOD; the process does not include infrastructures and materials) (http://www.lcafood.dk/database). The FU for comparison is $10 m^3$ of wastewater (from triphasic olive mill with recirculation water, that contains a maximum of about 3500kg of COD) and Impact 2002+ method has been used. The results of comparison analyse are synthetically illustrated in Fig.6.

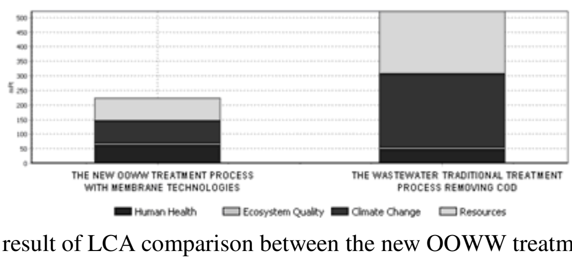

Figure 6: The weighting result of LCA comparison between the new OOWW treatment process with membrane technologies and the traditional wastewater treatment for to remove COD pollutant [FU: 10 m^3]

The preliminary result of sensitivity analysis show that the LCA of new OOWW process is less impacting for an overall percentage of 57% respect to traditional process.

4. Conclusions

The improvement of innovative physic-chemical processes, with high performances and low environmental impact, is important for a sustainable development. In this perspective membrane technology can offer important new opportunities in the design, rationalization and optimization of processes, products and wastewater treatments. In particular, the main advantages of the membrane technology system studied are that: the discharge level is almost equal to zero, that treats wastewater and at the same time produces the "novel products" and finally, the environmental assessment of novel products and processes is important for "novel food" producers, since they have introduced sustainability as a core company goal.

The preliminary result of impact assessment showed that the energy consumptions are the most significant impacts, therefore next aim of the study could be to improve the system to reduce the use of energy from non renewable resources. Hence the categories where impact are more significant are Climate Change and Depletion of Resources. A sensitivity analysis was undertaken to compare the new technology with the traditional wastewater treatment for to remove the COD pollutant. The result of the preliminary sensitivity analysis show that the LCA of new OOWW process is less impacting for an overall percentage of 57% respect to traditional process.

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The Environmental Certification of agri-food products: LCA of the extravergin oil

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ABSTRACT

Today has recognized broadly importance to appraise the connected environmental impacts to the agri-food production, it's to local level that global. The agricultural production and the transformation of the destination of use of the territory are between the human activities that contribute to the global climatic change sensitively. In consideration of this, it results evident the importance to apply in this sector instruments for improvement of safety and the environmental performances of the products. Between these tools, in Italy it finds wide application of the LCA (Life Cycle Assessment) methodology in the agri-food sector. It appraises the environmental impacts produced by the whole cycle of life of the products/process, in particular in the optics of the definition of the PCRs (Product Category Rules) for the editing of the EPD (Environmental Declaration of Product). Through LCA's study implement on the product, it is possible to individualize the consumptions of resources and energy and the environmental impacts produced in the whole cycle of life, beginning from the extraction of the first subjects, through the process of production, distribution, use and end-life, foreshadow LCA as a complementary tool of environmental management systems. The present study effected on extra-virgin oil of olive gotten by olives produced in the region of Lazio take place with a broadly mechanized cultivation system, the objective it is set to individualize the principal impacts produced by the cycle of life and to define the bases for the realization of the PCRs for this category of product.

Keywords: LCA, extra-virgin oil of olive, agri-food sector

1. Introduction

Olive oil is an oil obtained from the olive (*Olea europaea*; family Oleaceae), a traditional tree crop of the Mediterranean Basin. It is commonly used in cooking, cosmetics, pharmaceuticals, and soaps and as a fuel for traditional oil lamps. Olive oil is used throughout the world, but especially in the Mediterranean.

Over 750 million olive trees are cultivated worldwide, 95% of which are in the Mediterranean region. Most of global production comes from Southern Europe, North Africa and the Near East.

World olive oil production in 2008-2009 was 2.767 million tonnes, of which Spain contributed 40% to 45%. Of the European production, 93% comes from Spain, Italy, Portugal and Greece. Olive oil is a product of exceptional nutritional value, its production is associated with several adverse effects on the environment. Both olive tree culture and olive oil industry stages produce large amount of by-products, including pruning and harvest residues and solid and liquid wastes from the olive mills. Furthermore, both the agricultural production of olives and their processing into olive oil consume significant amounts of natural resources and energy. In addition, many sub-processes of olive tree cultivation, such

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as soil management, fertilisation and pest control, are potential sources of significant emissions into air, water and soil, not to mention any hidden processes associated with olive oil production, such as the production and transportation of agricultural inputs.

2. Life Cycle Assessment

Life cycle analysis (LCA), is a method for evaluating the environmental impacts of products holistically, including direct and supply chain impacts. The International Organization of Standardization (ISO) began publishing the 14000 series of Environmental Management System (EMS) standards in 1996. Since then the ISO14000 series have been rapidity adopted globally, with more than 36700 certifications awarded in 112 countries or economies. One of the most important elements of ISO14000 is the 14040 section on life-cycle-assessment (LCA), which is widely referred to in other ISO14000 sections such as the ISO14020 section on environmental labels and declarations. ISO14040 presents a basic framework to objectively evaluate the environmental aspects of a product taking its whole life-cycle into account and provides the rationale fro environmental labels and declarations including type I, II and III programs, many of which have been or are being incorporated into legal systems of countries such as Sweden, Japan, South Korea and the Europe Union.

The LCA applied to food products is affected by some technical hitches. Concerning the agricultural products, it is quite obvious that the production is rigorously related to climate conditions. It means that the specific impacts can sensibly change from one year to another. Furthermore, wine making is made up many different phases that can vary enormously from one producer to another, depending on the desired wine quality. It implies that the results of LCA regarding the production of different wineries are generally difficult to compare.

This study aims at the environmental optimisation of the production process, thus all subsequent stages of the olive oil cycle, packaging, distribution, use and end-of-life, have been excluded.

Fossil-based energy use, water treatment and use and the production, supply and application of other pre-farm inputs for the cultivation of olive trees such as fertilisers and pesticides are relevant environmental considerations. Thus they were included within the system boundary. Olive processing stages consume water and electricity and generate wastes and thus, they, as well as their waste management practices, are accounted in the LCA system.

The electricity used in all activities is being generated at a power station for which fossil fuels are consumed and emissions and waste are generated. The generation of electricity used by any process within the boundary is therefore included. The electrical energy flows are traced from mining and extraction of fossil fuels, processing, production and distribution to the grid at the points of use. This approach is more acceptable where a plantation is naturally occurring, e.g. a natural forest where every intervention on the forest should be considered as an intervention to the environment.

3. Olive Oil Production

The Latium agricultural and food- field, also showing signs of increase and conserving strong potentialities, have still many elements of criticalities that demand a specific engagement, also for the benefit of the hundreds of enterprises and the thousands of workers involved in the field. The cultivation of the olive tree is diffused on all the regional territory for a total surface of approximately 87.168 hectares, than it is extended from the sea level until beyond the 700 meters of altitude, representing almost 50% of the entire destined surface to the arboreal cultivations from fruit, comprised the screw, thanks to its remarkable variability and climatic, biological, agronomic adaptability, social and economic associate. Remaining in terms of superficial invested, the whose entity on a national level remains more or less constant in years (1.162.000 has), to the Lazio is up 7.5% of the national surface.

Table 1: Area and productions of olives Italian and Latium

	Tot. Area (Ha)	%	Prod. Area (Ha)	%	Prod(Ha)	Tot. Prod. (t)	%	Havested Prod.(t)	%
Italia	1.162.16	-	1.135.546	-	2.61	2.969.236	-	2.890.692	-
Lazio	87.168	7.5	86.542	7.6	1.37	118.273	4.0	100.597	3.5
Frosinone	21.010	24.1	20.944	24.2	1.35	28.274	3.9	27.426	27.3
Latina	12.83	13.9	12.064	14.0	0.93	11.212	9.5	9.021	9.0
Rieti	23.975	27.5	23.844	27.6	1.98	47.187	39.9	37.750	37.5
Roma	12.600	14.5	12.600	14.6	1.43	18.000	15.2	15.500	15.4
Viterbo	17.500	20.1	17.000	19.7	0.80	13.600	11.5	10.900	10.8

However the optimal conditions of cultivation are those where the temperatures minims do not come down to 5 degrees under the zero, advanced the annual medium rainfall or to 500-550 millimeter, the nature of the land or of mean-paste, with wealth of organic substance and neutral reaction or "subalcalina".

Table 2: Incidence % olives cultivar

	FROSINONE	**LATINA**	**RIETI**	**ROMA**	**VITERBO**
Moraiolo	50%	5%	5%	5%	5%
Rosciola	20%		5%	5%	
Marina	5%				
Leccino	10%	10%		10%	20%
Frantoio	5%	5%	15%	10%	20%
Strana		70%	10%	3%	
Carboncella				50%	
Salviana			50%	5%	
Raja			5%		
Sirole			5%	5%	
Canino					50%
Other	10%	10%	5%	7%	5%

The olive tree is present in enough homogenous way on all the regional territory; in particular, Rome and Viterbo are the province with a greater olive surface covering, respective, 28% and 24% of the entire regional surface. The medium production of olives obtained in the 2009 and destined one to the milling is gone around the 100,600 t. The yield in oil appears rather variable on the regional territory oscillating from a minimum of 12% to a maximum of 18%. The Latium olive oil is characterized by a diversified variety choice due to the adaptation of the cultivar in area which marked from details characteristics of the ground and the climate. The quality of extra virgin olive oil depends on a number of factors, each equally important, which include both the phase of the cultivation of the olive tree, with all the operations needed to ensure the quality of the production of the olives, and the phases subsequent to the olive picking, the storage and transformation of the olives into oil.

4. Results

The system model was developed and analysed by SimaPro version 7 software. The analysis has shown that for the production of 2.45 kg of olives required for the extraction of 1 l of "A1" - extra virgin olive oil in the territory of Vetralla (province of Viterbo – Italy), 0.0095 "1-tree planting" and 0.35 "1-tree pruning" operations are undertaken.

The latter produces 6.23 kg of pruning residue, which is subsequently burned, producing 28 g of ash. The ash is disposed to agricultural land. Furthermore, for every litre of olive oil produced, 1.82 m3 of water are extracted from wells in thrds, 76.9% of which for irrigation purposes. In addition, 96.4 m2 of agricultural land are ploughed. In regards to energy consumption, the agricultural stage consumes 2.35 kWh of electricity per litre of olive oil produced. This power is generated by diesel fuelled on-site electricity generators. Diesel consumption, which also feeds agricultural tractors, amounts to 127 g, whereas another 50 g of petrol are consumed for the operation of chainsaws per litre of olive oil produced.

The processing stage, on the other hand, only consumes 0.23 kWh of grid electricity and 3.51 l of water for every litre of olive oil produced. This stage, however, also produces 4.34 kg of liquid waste and 2.07 kg of moist pomace for every litre of olive oil produced. Although the latter is utilised as fuel for boiling water for the malaxation process, this energy demand itself is limited, and as a result in the absence of other form of utilisation, 0.91 kg of dry pomace end up as waste. The contribution of the various processes of the system in the consumption of crude oil and fresh water as well as the emissions of carbon dioxide, nitrogen oxides, sulphur dioxide to air, BOD and COD to waters and cadmium and zinc to soil are discussed in the following sections.

4.1. Consumption of crude oil

The analysis has shown that the system consumes 495 g of crude oil for the production of 1 l of olive oil, of which 434 g (87.6%) are consumed in agriculture related processes of the system and the rest in the olive oil processing stage. Within the system, crude oil is consumed in almost all processes, from the production of agricultural inputs to transportation, electricity generation, etc. The stages which most heavily consume crude oil are fertilisation and pest control as they consume 160 g (32.3% of the overall consumption) and 91.4 g (18.5%) of crude oil per litre of olive oil produced, respectively.

Table 3: Crude oil consumption in grams and % process contribution to overall consumption

	Olive oil processing	**Irrigation**	**Soil manag.**	**Fertilisation**	**Pest control**	**Pruning**	**Other**
Oil "A1"	61,4 (12,4%)	55,9 (11,3%)	74,5 (15,1)	160 (32,3%)	91,4 (18,5%)	49,7 (10%)	2,1 (0,4%)

4.2. Consumption of fresh water

The olive oil system consumes a total of 3914 l of fresh water for the production of 1 l of olive oil. Despite the perceived importance of the olive oil processing stage, especially with the use of three-phase centrifuge technology in Vetralla Zone, the analysis has shown that the 54.1 l of water consumed per litre of olive oil only account for 1.4% of the overall consumption. Irrigation is, naturally, the highest water consuming process, as it uses 1810 l of water (46.2%) per litre of olive oil produced, followed by pest control and fertilisation, which are accountable for the use of 1040 (26.6%) and 1010 l (25.8%) of fresh water, respectively.

Table 4: Fresh water consumption in litres and % process contribution to overall consumption

	Olive oil processing	**Irrigation**	**Fertilisation**	**Pest control**
Oil "A1"	54,1 (1,4%)	1810 (46,2%)	1010 (25,8%)	1040 (26,6%)

4.3. Emissions of fossil carbon dioxide to air

Carbon dioxide is an important greenhouse gas, which is derived from multiple natural sources such as fermentation and cellular respiration of various microorganisms (biogenic carbon dioxide) and man-made sources like combustion of fossil fuels for power generation and transport and burning of forests (fossil carbon dioxide).

Table 5: Emissions of fossil CO_2 in grams and % process contribution to overall load

	Olive oil processing	**Irrigation**	**Soil manag.**	**Fertilisation**	**Pest control**	**Pruning**	**Other**
Oil "A1"	237 (61%)	616 (15,8%)	803 (20,6%)	1040 (26,7%)	279 (7,2%)	909 (23,3%)	16 (0,4%)

		Oil "A1"
Fertilisation	Fertiliser production	932 (23,9%)
	Fertiliser transportation	101 (2,6%)
	Fertiliser application	7 (0,2%)

4.4. Organic load to water

Dealing with COD (and BOD) emissions in a life cycle system raises two concerns. Firstly, both COD and BOD are not specific substances but indicators of the presence of various organic substances, which may also be quantified under a different emission category. As a result the inclusion of either COD or BOD in a process inventory may result to double counting and for this reason these are not included in most standard life cycle impact assessment methods.

Table 6: Emissions of COD in grams and % process contribution to overall load.

		Olive mill power generation	**Liquid waste treatment**	**Fertilisation**	**Pest control**	**Other**
Oil "A1"	COD	0,8 (4,7%)	12,6 (73,7%)	2,3 (13,5%)	1,3 (7,6%)	0,1 (0,5%)
	BOD	0,8 (8,6%)	5,2 (54,1%)	2,2 (23,5%)	1,3 (13,2%)	0,1 (0,6%)

More than 73% of the total load is released into the environment when liquid wastes from the olive mill are disposed to evaporation lagoons, mainly due to groundwater contamination from leaks in transfer pipes and potentially poor performance of the impermeable clay layer with which evaporation ponds are supplied.

5. Discussion and Results

The results presented illustrate the complexity that characterises the scientific evaluation of the environmental performance of a food product system due to its extensive overlap with other product systems. In this study, this complexity was supplemented by the poor availability of region-specific and specifically agriculture related LCI data. Based on the results of the study, individual processes of the overall system were classified into priority categories according to the effect their potential optimisation could have in the optimisation of the olive oil production system, as summarised below:

- Tree planting, olive collection and transportation of olives to the processing unit do not raise any concern as their contribution to all environmental flows considered was less than 0.5%. Thus, their optimisation is not considered an effective way of optimising the system.

- Pest control and soil management are relatively evenly distributed between raw material consumption and emissions of various pollutants to environmental compartments. Environmental loading from soil management, in the other hand, is mainly in the form of oil consumption and exhaust emissions from the operation of agricultural tractors.

- Irrigation and pruning processes are major consumer of fresh water in the system, most of the other environmental flows arise from the mechanical extraction of water from wells since the heavy operation of diesel fuelled electricity generators which feed turbine pumps consumes a significant amount of fossil fuels and releases significant quantities of air pollutants. Similarly, pruning itself consumes fossil fuels during chainsaw operation; nevertheless the attention should be drawn on residue management since burning pruned branches is a major polluting activity.The environmental optimisation of the fertiliser producing industry is an issue of a wider (than the olive oil system) scope and could, by itself, be the subject of further research.

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Life Cycle Assessment of wine production

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ABSTRACT
Environmental management foresees that firms not only organize a system based on the prevention of operating outside the boundaries of the law but also on a program of continuous improvement of business behavior towards the environment. Life cycle assessment (LCA) as a method to support these systems enables otherwise invisible aspects to emerge that allow revising and optimizing the use of resources such as reducing energy or water consumption and other more general issues. This paper has as its objective to expose the advantages resulting from the use of the Life Cycle Assessment method in the wine production sector, with particular reference to wine production in the Tuscany region.

Keywords: LCA, wine, production, life cycle, environmental impact.

1. Introduction

The wine industry is an important segment in the economy of some countries particularly in the Mediterranean area. Wine production has traditionally been seen as an environmentally friendly process. However, it requires a considerable amount of resources such as water, energy, chemical substances and organic amendments and produces a large amount of wastewater and organic waste. The wine production process is a complex phenomenon that starts with the planting of vines, passes for extractive activities juice from the grape to then arrive toand thereafter distribution and sale of the bottled and distributed on a different scale (Vinci *et al,* 2003). Estimating the environmental impact of this kind of product is not simple since it entails a number of activities, developing an understanding of the various direct and indirect production methods and hence the varying consumption of energy and raw materials and impacts on the environment in terms of emissions and waste. The products placed on the final market have a number of different characteristics, and multiple physiological differences due to the many influencing factors. Precisely for this reason, we must specify the source of the product analyzed and describe its characteristics (Halberg, 2003).

2. Life Cycle Assessment

Life cycle assessment is a quantitative approach that assesses a product’s impact on the environment throughout its life cycle. LCA attempts to quantify what goes in and what comes out of a product from “cradle to grave,” including the energy and material associated with the extraction of materials, product manufacture and assembly, distribution, use and disposal, and the resulting environmental emissions. LCA applications are governed by the ISO 14040 series of standards. LCA applied to food products is affected by several technical

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issues. The production of agricultural products, as is rather obvious, is rigorously related to climatic conditions. This means that the specific impacts can change perceptibly from one year to another.

The boundaries relating to nature commence with the cultivation of wine grapes and conclude during the consumption phase as well as including land filling and recycling stages (for packaging), in each process phases. Waste packaging materials are also considered as outputs if recycling processes are not included. Concerning geographical boundaries, the Tuscany region is the territory considered for the study. Furthermore, wine making involves many different phases that can vary enormously from one producer to another depending on the wine quality sought, and implies that the results of an LCA of the production of different wineries are generally difficult to compare. According to the international standards ISO 14040 series carry out the life cycle steps that have been considered in this study. In particular, the phases considered are grape cultivation and transport, wine production and storage, bottling and packaging activities, and the transfer of the final product. However, the three main stages i.e. wine production, glass production and transport have similar responsibilities in terms of work wear and fossil fuel impact on the environment. Nevertheless, it is difficult to improve the life cycle of wine by focusing only on transport and glass production since the former is related to distance and the latter is a fixed process. Thus, improvements in the life cycle of wine are concentrated on production. The data collected includes numerous assumptions made by the research team due to the lack of available data (Ardente *et al,* 2006).

The specific aims of this report include the extent to which activities consume energy, introduce wine production emissions, and identify the crucial wine production activities/stages with the largest impacts. According to the ISO standards, a system boundary is determined by an iterative process in which an initial system boundary is chosen and then further refinements are made by including new unit processes that are shown to be significant through a sensitivity analysis. In delineating the boundaries, the system comprises all stages of production including the bottling phase and the potential impact of recycling. No account is taken of transport to the various distribution markets.

The information for wine producers focuses on increasing knowledge on the product's environmental strengths and weaknesses, product and process development areas, their environmental assessment, aspects and efficiency possibilities, providing information to the market place with further details on environmental management systems in place, conveying a more in-depth view of their own production process, and possibility of danger of Eco-labeling and market expansion. The analysis was undertaken using the LCA software system and public international databases. As the report comprises only outputs and inputs relating to the LCA system of wine, it is assumed here that there are no allocation issues although some procedures are automatically included in accordance with the LCA software calculation. The objective of the entire process is to produce wine for consumption and since the final product that the customer buys is a bottle of wine the most obvious functional unit employed throughout the report is 1 liter of wine (Functional Unit: 1 liter of wine).

The identification and selection of impact categories generally depends on the goal and scope definition. The information collected during the inventory procedure, the amount and quality of data and limitations of the software data catalogue greatly influence these procedures. The wine life cycle model includes several sources of information of emission datasets. Two main sources of information for the inventory procedure should be distinguished: resources and emissions automatically included in the software database (for instance pollution and irrigation resources, land filling etc.) and information gathered through analyzing and calculating environmental reports from European companies. These categories must be divided into sub-categories for a more operational and practical application. During the inventory impact assessment phase, the following main environmental impacts for the life cycle considered can be obtained: global warming, ozone layer depletion, acidification, eutrophication, photochemical oxidant formation and depletion of fossil fuels and minerals (Goedkoop, 1999). In the Inventory Analysis, the inventory is translated into potential contributions to various impacts within the main groups of predefined impact categories. During this phase, an attempt is made to identify related hazards, thus assisting manufacturers to prioritize areas for action.

3. Wine Production

Wine is the product of the total or partial alcoholic fermentation of fresh grape juice resulting from a number of production methods depending on the type of wine desired. Wine preparation also includes numerous additives (Notarnicola *et al,* 2003).

Wine production is a lengthy and complex process that entails several trial and support processes starting from the cultivation of the grapevine to bottling, to the sales activity of the final product. The nature and environmental impacts differ. Wines in commerce are classified as: wines of Controlled and Guaranteed Denomination of Origin (CGDO), wines to Controlled Denomination of Origin (CDO), wines to typical geographical indication (TGI), table wines and special wines: liquorized, sparkling, fizzy, aromatized wines.

While the first two classifications are obtained from cultivating grapes according to the production disciplines in specific zones, submitted to chemical physicist examinations and constituting the characteristics of the official bodies that guarantee its typicality and quality, TGI wines must be produced with a guaranteed 85% of grapes picked in the geographical zone from which they take their name. Sparkling and fizzy wines are characterized by small bubbles of carbon dioxide produced by natural fermentation or obtained with the addition of gas and identified as such on the label.

The Tuscany wine region extends south from Florence. Some of the best-known Italian wines come from this region and the most important are Chianti and Brunello di Montepulciano. The rising trend to create Cabernet Sauvignon or blended wines, has led to the unofficial “Super Tuscan” designation for these expensive and much sought after wines. Sangiovese is the main red wine grape of the region. Malvasia is the main white grape in terms of quality and the Trebbiano grape in terms of quantity. In this region, the different vineyards and firms of the sector apply very different production systems. Some produce wine using organic farming methods while others use industrial methods. In particular, the Sangiovese vine species has an expected average lifespan of 30 years and full production is achieved in the fourth year. The average yield per hectare is approximately 5 tons of grapes per year. The machinery employed in vineyards is used to carry out ordinary vineyard operations and their maintenance takes place in in-house garages. Production practices are based on the laws established by farming regulations, utilizing natural chemical products in agricultural practices aiming to comply with plant production, or chemical products such as fertilizers and pathogenic agents.

The interpretation of the inventory results phase and the evaluation of impacts, ISO 14043, serves to obtain improvements in the environmental performance of the system under revision.

The production stages flowchart was studied to assess the inputs and the output of energy and materials. Successively, indirect environmental burdens related to material production and energy sources, as well as to raw materials and final product transportation, were estimated. The materials included in the analysis are organic manures, fertilizers, sulfur, plant protection, sodium carbonate, perlite and bottling materials.

Table 1: The general wine production steps

Harvest	The grapes are picked when they are ripe, usually determined by taste and sugar readings.
Crusher:	This removes the stems from the grape bunches and crushes the grapes (but does not press them) so that they are exposed to yeast fermentation and the skins can impart color to the wine.
Fermentation	Yeast primarily turns the sugar in the wine into carbon dioxide, heat and alcohol.
Maceration	This is the process where the phenolic materials of the grape - tannins, coloring agents (anthocyanins) and flavor compounds - are leached from the grape skins, seeds and stems into the must.
Pumping Over	Skin and other solids float to the top and need to be pushed back down to stay in contact with the must. This "cap" can be punched down with a tool, or the must can be pump up form the bottom over the cap and submerged that way.
End of Maceration	The winemaker must decide if the must has sat long enough.
Remove Free Run	The best quality wine is made only from the juice portion of the must.
Press	This squeezes the remaining juice out of the grape. Low quality wine is obtained if this is done too hard or too often.
Settle	The juice, now wine, needs to settle after this ordeal.
Racking	Moving the wine from one barrel to a new barrel allows extracting the solids and anything that might cloud the wine.
Malo-Lactic Fermentation	This secondary fermentation can turn the tart malic acid (of green apples) into the softer lactic acid (of milk). Many, but not all red wines go through this step.
Fining	a process that helps remove anything that may be making the wine cloudy.
Filtering	A process that removes any fining agents or any other undesirable elements in the wine.
Bottling	This must be done carefully to ensure the wine does not come into contact with air.
Storage	Finer wines may be stored for several years in bottles before they are released.

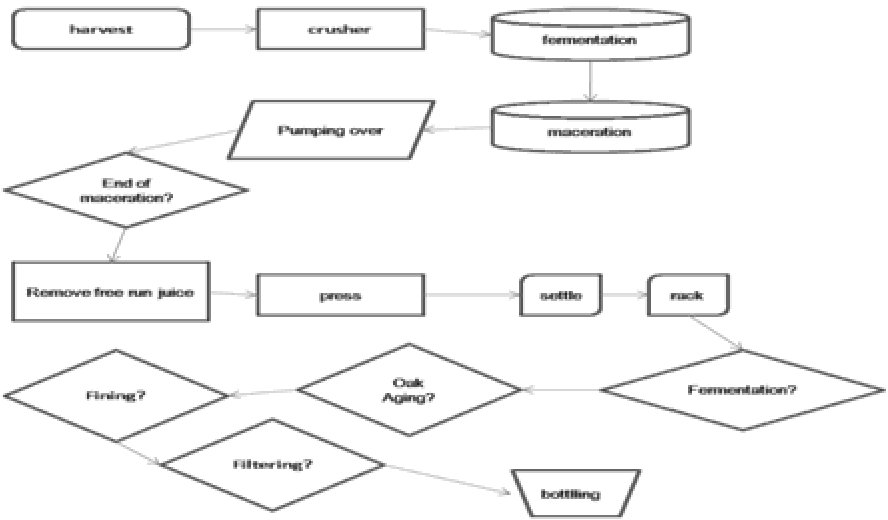

Figure 1: Flowchart of wine production

The energy sources exploited are fuels used by the agricultural machinery, electricity used during each winery transformation, LPG used to produce steam and hot water to heat buildings and diesel oil used for the transportation phase, the latter referring to the production processes of the materials and energy sources employed.

4. Results

After the inventory phase, in accordance with the ISO 14040 standards, we assessed the inventory data to discuss the results (ISO 14042). This phase consists of the evaluation of the significance of potential environmental impacts, associated with data deriving from the inventory phase in relation to the aims of the analysis.

The results interpretation phase of the inventory and evaluation of impacts (ISO 14043) serves to identify improvements in the environmental performance of the system under study. Environmental impacts are initially classified and thereafter placed in relatively homogeneous impact categories. Finally, the assignation of the level of importance for each impact categories is required for a correct analysis. The main environmental impact categories considered concern the use of resources, human health and pollution consequences.

Table 2: Input in wine production (g/F.U.)

	PLANTING	WINE PRODUCTION	STORAGE	BOTTLING	GRASS RECYCLING
Steel	395	2250	12500	1354	
Fuel	5055	45000		1620	
Fertilizers	3615	25055			
Pesticides		9395			
Electricity			18	25	
Chemicals			130		
Glass				309130	6800

The electricity consumption aspect is noteworthy and could be reduced with the use of structures with modern energy efficient installations. Given the simplicity of their components, the use of chemicals product, fertilizers and pesticides, which are the principal cause of land pollution, have no substantial bearing on emissions. In the bottling storage phase, the most important input is the steel of the machinery used, glass for bottles and fuel for the energetic input. In the last phase, most of this farm repair with glass recycling and it has used fuel like energy power but make up again utilizable glass material. This situation refers to the Italian reality. Around 40% of glass used for bottling is recycled while the remaining part is burned and the ash is placed in waste disposals. The traditionally more impactful phases are bottling and transport (which in this study were excluded from the boundaries of the system) and the analysis reflects these results.

Table 3: Emissions in wine production (g/F.U.)

	PLANTING	WINE PRODUCTION	STORAGE	BOTTLING	GLASS RECYCLING
NO x	285	3775	30	1250	292
VOC	50	575	190	1120	46
CO	90	1225	15	11	104
PM10	50	475	320	5410	37
H20	7400	97600	0	0	8405
CO2	19000	240800	38700	254025	20374
SO x	35	400	130	2610	37

Concerning emissions, we can state that the greatest quantities of emissions are due to the production process. In particular, carbon dioxide in all phases of the process. In conclusion, efforts should focus on the environmental impacts associated with wine production (grape harvesting and winery activities).

5. Conclusions

There is no doubt of the importance of the evaluation of an agricultural system and in particular environmental sustainability. In general, the environmental analysis of the wine industry shows that the main effluents of the sector, beyond the use of fossil fuel, are wastewater and organic solid waste. Problems associated with waste generation in the wine industry are of special relevance during grape harvesting (José *et al* 2007). However, in this sector the use of large amounts of chemical fertilizers and organic matter generates the possibility to recover organic waste from the vineyard and may be presented as a sustainable strategy for waste management. The LCA method is a valid tool to study environmental systems behavior. The high amount of organic waste generated in wine production makes it interesting to evaluate new management procedures. The use of renewable resources, sunlight and wind, could be a solution to decreasing fossil fuel consumption. Given that fossil fuels account for the largest impact in the life cycle of wine production, the relative magnitude of the processes impacting on fossil fuel consumption was subsequently measured.

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Life Cycle Assessment of Sicilian peach sector

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ABSTRACT

This paper presents an analysis of the Life Cycle Assessment applied to a peaches and nectarines production cycle with a low cold requirement and a precocious maturation. This fruits are produced by a farm located in the Sicilian district of peaches near Caltanissetta. This study, as well as disciplined by norms ISO 14040 series, provides a systematic evaluation of all the environmental impacts derived from the single phases of the life cycle of a product/service and a particular attention has been devoted to Life Cycle Inventory inherent fertilizing soil phase. The functional unit was 1 kg of peaches.

Keywords: Peach sector- LCA- Environmental impacts- Soil fertility- Transportations.

1. Introduction

Although the strong international competition, the Italian peaches growing is considered the most important one among the western productive countries and it is just second compared with the Chinese production. The aim of this paper is the application of the LCA life cycle analysis to the Sicilian peaches sector using as reference the productive process of a dedicated farm located in the eastern Sicily in the district of Caltanissetta, an area where this cultivation is particularly developed; inside this farm there are quite 10 hectares of peach orchards characterized by medium and tardy cultivars and with a production period which begins in the last ten days of August and ends in the last ten days of October and which uses an integrated cultivation method: in total 19.000 plants of peaches and a yearly production of 43.000 quintals (Palmieri A., Pirazzoli C.,2009).

In this study has been identified, quantified and analyzed the main environmental impacts associated with the cycle of the starting process of the cultivation of the trees of two different cultivars, medium and tardy (Baldo G. *et al*, 2005). In particularly. it has been quantified the plant-protection products and the fertilizers used in the different treatment steps in order to obtain a precise identification of the pesticides, fertilizers and weed killers characterization factors. Afterwards it has been analyzed the peaches working process into the studied farm with a particular interest in the quantification of the energy consumptions, of the water resources and of the packing.

2. Experimental part

The study has been done following the LCA procedure indicated by the 14040 European rules and it is articulated into the following four main steps:

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1. Definition of the goal and of the application field of the study; this last part is also articulated in the definition of the functional unit and in the system frontiers;
2. Inventory analysis of the life cycle which clearly interests the starting phase of the study: it means the data collection;
3. Evaluation of the life cycle impact (LCIA - Life Cycle Impact Assessment);
4. Life cycle interpretation (LCI - Life Cycle Interpretation).

2.1 Goal and application field of the study

The aim of this paper is the identification and the analysis of the main environmental impacts associated to the life-cycle of a kilogram of peaches of two different cultivar, medium and late kind of peaches depending on the periods of fruits picking. In order to supply a reference for all the input and outputs data, relative to the aforesaid life-cycle, and in order to guarantee the comparison of the results, for each of the two analyses the same work unit has been identified, according to the ISO 14040 norm. To this aim the methods of cultivation at first of an hectare of peach cultivar medium and successively of peach area cultivar late have been analyzed, both with a useful life-cycle of 15 years being therefore able to compare the obtained result and to characterize the less impact solutions, and to propose improvements. For the life end of the orchard the scene of compost in the field has been assumed. For the phase of working in the industrial plant, instead, the data of the cultivar of the worked peaches has been unified, since the amounts of input of the system turn out equal. For the plant of working, a time horizons of 30 years has been assumed. Among the analyses, two important processes have been pointed out: the primary working and the following processing into the farm. In Tables 1 and 2 the flowcharts are reported and they refer to the main cultivating actions which have been adopted into the field (independently from the quality of the cultivated peaches) and to the working process phases of the products inside the farm, which is extended as far as 3000 square metres

2.2 Inventory analysis of the life cycle

The analysis of the inventory, from whose degree of detail depends the reliability of the final results and the accuracy of the eventual proposals of technical and environmental improvement, is characterized by the construction of tables able to represent as faithful as possible all the exchanges between the single operations of the effective productive chain.

The data used in the phase of the inventory of this analysis have been directly collected on the field of production and inside the working plant of the peaches, site in province of Caltanisetta in the Oriental Sicily (table 3). For both the phase of the cultivation of the field, differentiated according to the kind of cultivar of the peaches, and the phase of fruit working in the plant, same tables are introduced, showing the different amount of raw materials, pesticides, fertilizers and energetic resources, necessary for the different phases of the productive cycle and for transportation and waste. We emphasise the particular attention devoted to the evaluation of the electrical power consumption in the field and in the plant: that it turns out to be particularly high because of the presence of cooling freezer cells, and to the evaluation of the diesel oil and lubrificating oil necessary to the several treatments in field, between which the pruning, the fertilization, the plowing and the collection of the fruits.

Table 1: Phases of the primary working "Fruits growing"

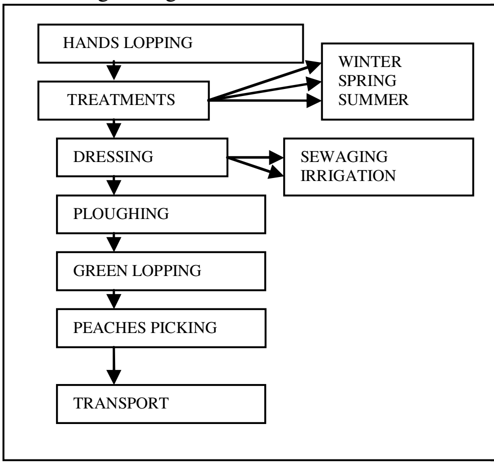
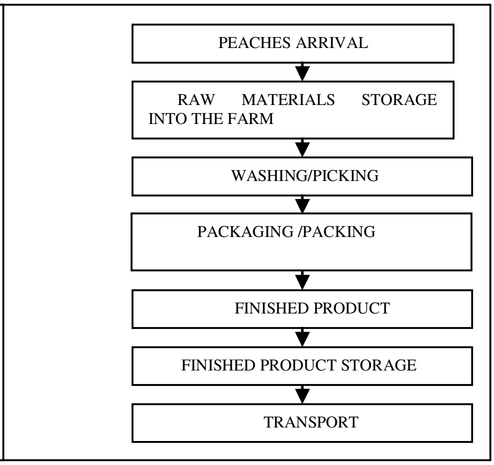


Table 2: Phases of the working process into the farm



Source: Data personal elaboration

Table 3: Input inventory Analysis on the field and inside the working plant

Pesticides	Medium Cultivar kg/kg	Late Cultivar kg/kg	Fertilizers	Medium Cultivar kg/kg	Late Cultivar kg/kg
Patrol 35 wp	0,000266	0,000218	**Ammonium sulfate**	0,009523	0,007792
Polithiol	0,002222	---	**Urea**	0,000952	0,000779
Warrant	0,000222	0,000181	**Calcium Nitrate**	0,000476	0,000389
Acuprico 90	0,000018	0,000015	**Magnesium Nitrate**	0,000476	0,000389
Agrooil	0,000879	0,000727	**Nitrate of potassium**	0,000317	0,000259
Proclain comby	0,001333	0,001090	**Nitro 34**	0,000793	---
Sulfur	0,000716	0,000332	**Calcium chloride**	0,000634	---
Mik	0,000222	0,000181	**Elecrtical data field**	Kwh 2,857142$^{-0,6}$	Kwh 2,848764$^{-0,6}$
Ganzo	0,000013	0,000008	**Elecrtical data working**	Kwh 0,179321	Kwh 0,225508
Karate zeon	0,000076	0,000043	**Water tratements**	Hl 0,00488888	Hl 0,00355844
Agrimix	0,000022	0,000013	**Water irrigation**	Hl 7,10714285	Hl 4,67532467
Deltametrina	0,000022	0,000013	**Water - working phase**	Hl 0,005948	Hl 0,0074803

Source: data personal elaboration

2.3 Life Cycle Impact Assessment

In this paper for the normalization and weighing phases of the environmental damage, it has been used an environmental evaluation method named IMPACT 2002+, a middle solution between the *midpoint-oriented* and *damage –oriented* methodologies approaches, reducing the results deduced by the inventory analyses to fourteen impacts categories which are also referable to four damage categories: *Human Health, Ecosystem quality, Climate change, Resources* each of them come from different impact category (Baldo *et al.*, 2005).

Table 4:Impacts and Damage categories into the Impact 2002+ method

Damage categories	Impact categories
Human Health	Human toxicity
	Respiratory inorganics
	Ionizing radiations
	Ozone layer depletion
	Photochemical oxidation
Ecosystem Quality	Acquatic ecotoxicity
	Terrestrial ecotoxicity
	Terrestrial acidification/nutrification
	Acquatic acidification
	Acquatic eutrophication
	Land occupation
Climate Change	Global warming
Resources	No-renewable Energy
	Mineral extraction

Source: data personal elaboration

In table 4 it has been reported: the impacts categories which concern the negative effects on the environment caused by a damage due to a process(second column); the damage categories obtained collecting the impacts into the macro categories which represent the environmental sectors which suffer a damage (first column).

Diagrams 1 and 2 show the results of the various categories of damage concerning the cultivation of the medium peaches cultivar (Diagram 1),collected in the month of August, and the late peaches cultivar (Diagram 2), collected in the month of October, obtained by the input data of the table 3 using the SimaPro software. Diagram 3, instead, shows the results of the various categories of damage concerning the working process inside the plant and also these result are obtained by the input data of the table 3 using the SimaPro software. The mainly meaningful category of damage is the human health, probably because of the high amounts of emissions in atmosphere due to the electrical power consumption of the freezer cells .

2.4 Life Cycle Interpretation

From the examination of the results shown in Diagrams 1 and 2 it is possible to see that in absolute the main impact categories of damage are observed in the cultivation of an hectare of peach of cultivar medium, while the activity that provokes a greater environmental damage for both primary processes is the irrigation of field. The category of damage mainly involved turns out to be the consumption of primary resources, probably due to the high consumption of energetic resources necessary to the cultivation processes. Instead, regarding the phase of working of the peaches in plant, from Diagram 3 we can see that the electrical power consumption turns out to be the main impact on the atmosphere, followed by categories of transportation of the raw materials.

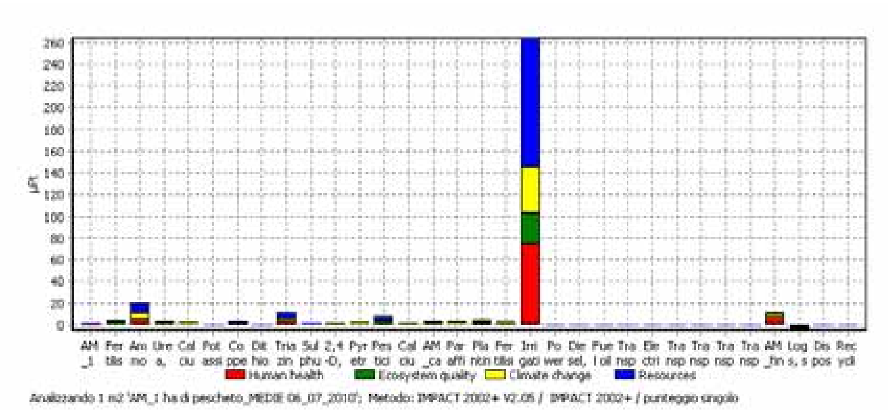


Diagram 1 : Categories of damage in the cultivation of the medium peaches cultivars. Source: data personal elaboration

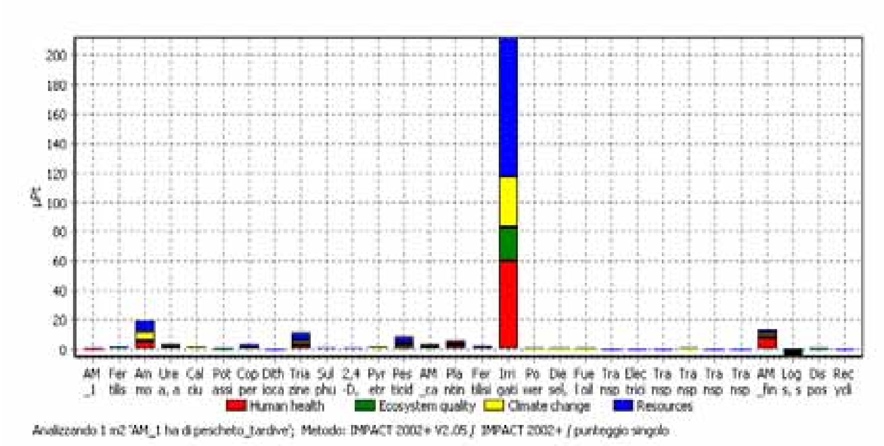


Diagram 2: Categories of damage in the cultivation of the late peaches cultivars. Source: data personal elaboration

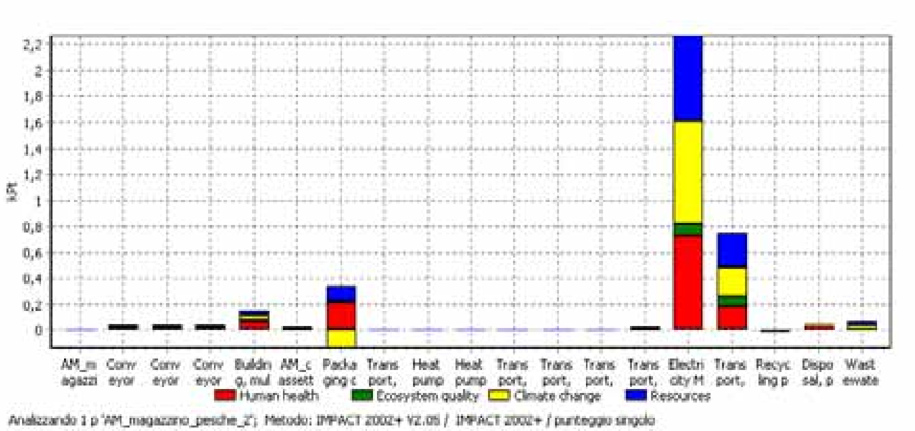


Diagram 3: Categories of damage in working process. Source: data personal elaboration

3. Conclusions

From the carried out study it emerges that LCA in the agricultural and food-rows turns out to be an optimal decision maker tool, able to identify the environmentally critical points of the fruits production in order to address the management towards opportunity of business improvement.

To this aim, more responsibility in producing and purchasing could be facilitated also through the use of appropriate ecological labels, from which the most meaningful features of the products clearly appear (Notarnicola *et al.*, 2008). From the results of the LCA analysis in the Sicilian peach field emerges clearly that in the phase of orchard cultivation the irrigation of the field mainly impacts with respect to the other phases; systems for the re-use of the water are therefore strongly suggested. Instead, during the phase of working of the fruit, the consumption of electrical power is the phase of the productive cycle with absolutely more impact in the environment; in order to decrease such a consumption, the installation in the plant of photovoltaic panels is recommended (Cordella and Santarelli, 2008). For sure, for a development of LCA analysis in the field, a more inherent investigation should be carried out with respect to various kinds of fruit packing, and different techniques of field fertilization and of transportation towards the distribution lines and the final consumer.

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Life Cycle Assessment of the Sicilian citrus fruit field

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ABSTRACT

The aim of this paper is to quantify the total environmental impact due to oranges life cycle (*cv. Tarocco*-integrated production) and, on the basis of the obtained results, to evaluate the possible improvements in the productive methodology.The reference firm is located in Sicily, near Catania and the study was conducted in accordance with the ISO standard 14040:2006, choosing one ton of oranges as functional unit. The system, object of the present study, includes the following phases: cultivation; harvesting; transport to the temporary storage and processing plant; processing; transportation to the selling points.

Keywords: Citrus fruit production, Life Cycle Assessment, Sicily, Environmental hotspots, Integrated fruit production

1. Introduction

Nowadays Sicilian oranges are becoming more and more difficult to find on the Italian market especially in the Organized and Great Distribution (OGD) because it's not easy to front the competition with oranges coming from other countries. A solution to this problem could be the developing of a new strategy campaign based on high efficiency criteria, making the system more competitive both on a national and on an international level. This efficiency should be, also, extended to the environmental sustainability through the use of specific indicators, such as the Life Cycle Assessment (LCA), which can be useful to identify the environmental improvement opportunities also in this field. It could be used to find new and alternative methods for the agricultural production which can reduce the environmental impacts, increasing the products sustainability.

Unfortunately, although in the last decade the dedicated uses of the LCA methodology into the food-processing field increased, the citrus sector is insufficiently weighed. The study carried out by Meissner Schau and Magerholm Fet (Meissner Schau *et al.*, 2008) reports a table in which the main LCA studies within the citrus sector have been listed from 1999 to 2006. It has to be added, also, the ones carried about: Pasta and couscous (Notarnicola B. *et al.*, 2001); Green Coffe (Coltro *et al.,* 2006); Olive oil (Fiore *et al.*, 2009).

Internationally speaking and concerning the citrus field, it has to be pointed out the studies carried out by Sanjuan. (Sanjuan N. *et al.*, 2005) and Coltro (Coltro L. *et al.*, 2009) which concern the environmental profile associated with the oranges production respectively in Spain and in Brazil. On the contrary, from a national point of view, it hasn't been recorded studies concerning this field except for a LCA study done by Beccali (Beccali M. *et al.*, 2010) about the products based on citrus fruits. In this context it can be included the present work whose aim is to quantify the total environmental impact associated with the oranges life cycle *cv. Tarocco* obtained by an integrated production.

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2. Firm presentation and citrus orchard description

The reference firm, located in the province of Catania in Italy, insists on a plot of about 12 ha (the productive ones are 10,8 ha) and has an average production of 2700 quintals every year.

The model of the examined citrus orchard is the same which today is adopted in the plain rational citrus orchards into the firms which have cultivated areas of about 10 ha. The trees are arranged in a square, with a distance of 5x5m, and so with a density of 400 plants for each ha. This makes the inter-rows more practicable and, at the same time, the mechanization level more efficient. The cultural life cycle lasts about 50 years and during 30 of them the production is full. The citrus orchard cultivation is done following the common techniques of integrated pest control whose aim is the environment preservation and the food security through the minimization of the use of synthesis chemical products and the control of the entire productive process. The field watering occurs under crown sprinkling with mean yearly consumptions of about 4600 m^3/ha; the origin of the used water used is phreatic and it is brought on the surface using a specific electric pump. The trees lopping is done one or two times on alternate years using a chain saw and pruning scissors; the fronds are left on the field in order to allow them to decompose and to turn into organic fertilizer, while the branches are used as firewood. As regards the yearly treatments done in the field, they consist in: three dressings every 40 days; three pesticide treatments; two weed-killing treatments. The fruits picking is done by hand: the product is put into crates and it is transported to the point charges using a towed vehicle.

3. Experimental part

The study was conducted in accordance with the guidelines and requirements of the ISO Standards 14040:2006, and it is divided into the following steps: definition of the aim and of the application field (which includes also the definition of the functional unit and of the system boundaries); the life cycle inventory analysis (LCI); the life cycle impact evaluation (LCIA); the life cycle interpretation (LCI).

The aim of this paper is to quantify the total environmental impact due to oranges life cycle (*cv. Tarocco* - integrated production) and, on the basis of the obtained results, to evaluate the possible improvements in the productive methodology.

Following the ISO 14040:2006 standard, the functional unit primary purpose is “to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results”. In this case 1 ton of oranges *cv. Tarocco* has been chosen as the main functional unit.

The main system boundaries include the phases of cultivation, processing and of the functional unit end life, considering also the transport by trucks of oranges from the field to the processing plant and from the processing plant to the distribution platform in the north of Italy. The step regarding the consumption by the end user is exempt from relevant impacts so it hasn’t been taken into account. As regards the end life, instead, it has been represented considering the exclusion of the no edible part (it means the peel) and assuming of doing the separate waste collection of the municipal solid waste and its recovery as compost.

With regards to the cultivation phase, it has been represented considering the citrus orchard life cycle and including it in the one ton fruit life cycle, for the related share. The fruit production coincides with the age of the plant: for a few years the production is of no use but then it increases, it reaches a peak value and it decreases at the end of the plant life cycle. That’s why the citrus orchard life cycle has been represented including, inside the system boundaries, the phases of planting, cultivation, harvesting e decommission. In particularly it has been considered: the production of chemical products as fertilizers, pesticides and herbicides and their transport into the field; the watering, dressing and weed killing treatments as well as the trees looping and the oranges picking including also the machineries and the related consumptions of resources, draw materials and electric power; the heat treatment of the special waste as well as the transportation to the dedicated plant; During the orchard decommissioning the recovery both of the trees trunks as firewood ad of the fronds and of the roots as compost. Unfortunately the impossibility to find reliable data about the cultivation phase into a nursery garden and the impossibility to find some more data into the current sector literature it has not allowed to insert it into the system boundaries.

As regards with the second phase, the processing plant life cycle has been taken into account. Starting from its life and from the average quantity yearly processed, this has been included in the oranges life cycle for the amount associated to it. In particularly it has been considered: all the working steps starting from the oranges reception from the field till their packaging and their transfer to the distribution platform. These steps have been described taking into account the related consumptions of raw materials, resources and electric power as well as the main machineries; the warehouse built in reinforced concrete and where the processing activity is done; the waste associated with this process.

Considering the used machines, the essential thing is that most of them are specific to process the citrus fruits and so they are not mentioned into the used software database except for the conveyor belts: since this, they have been considered in the calculation of the total electrical energy consumption. Regarding the conveyor belts, there are 10 inside the plant and 9 of them are 13m long while 1 is 40m long. For this study, in particularly, the type of belt is always the same and so it has been included just one item ("conveyor belt, at plant") associating to it all the lengths and supposing for it a time life of quite 15 years. The so mentioned word includes the most important materials, the transportation of the new parts to the assembly plant and of all dismantled parts at the end of life either to the secondary metal producer or to the disposal site. No disposal of metal is included as it is recycled. Disposal of concrete from foundation and conveyor rubber band are included. No energy for assembling is included. The working chain life is quite 30 years long. At the end of it, it has been supposed the conveyer belts decommissioning, after their replacement and the warehouse dismantlement.

The great part of the data used to realize this study have been on field collected in collaboration with the skilled workers of the different plants involved, trying to guarantee, as much as possible, the same data quality. On the contrary, the data not directly found have been gathered from specific literature upon the check of their reliability. All the useful comparisons have been developed, as it is reported into the ISO 14040:2006 rule, considering the same: functional unit; system boundary; data quality.

4. Results and discussion

4.1. Introduction

In the examined case, the damage evaluation (LCIA) has been done including both the mandatory elements, as provided in to the ISO 14040 and 14044, and the optional ones in order to express the results with equivalent numerical parameters able to show quantitatively the environmental effects of the considered system. The study has been realized with the Simapro 7.0 software in its more up-to-date version choosing, as the used method, the Impact 2002+ one because, in our opinion, it has more understandable settings for the insiders and it is also easily open as regards other methods. It has the following advantages: it calculates the not-renewable energy consumption which represents a main aspect in range of similar studies; it recognizes the CO_2 as the biggest responsible of the greenhouse effect , considering it as a characterization of the Climate Change. This method offers an intermediate solution between the *midpoint- oriented* and the *damage-.oriented* approaches bringing the results obtained by the inventory analyses into 14 impacts categories which are also divided into 4 damage categories.

4.2. Life cycle impact evaluation

The whole damage counts 7,53 * 10^{-5} pt and it is principally due for the: for the 45,20 % to citrus orchard life cycle, for the share of about 1t of oranges; for the 29,00 % to the transport of the oranges from the warehouse to the distribution platform in the North of Italy; for the 12,80 % to the transport of the oranges to Sicily; for the 4,06 % to the processing phase (figures 1 and 2).

In terms of damage categories, the whole damage is divided as follows: 33,10 % Human Heath; 32,60 % Resources; 25,70 % Climate change; 8,65 % Ecosystem Quality.

In detail it has been reported and discussed the results for each damage category:

Human Health

The damage to the human health counts 2,49*10^{-5} pt and it depends :

a) for the 42,2 % to the emissions in the air of 837 mg of NOx, which: for the 42,3% associated to the citrus orchard life cycle considered for 1t of oranges and in particularly for the 33,90 % to the use of nitrogen as fertilizer, for the 24,4 % to the watering process, for the18,10 % to the dressing process and for the 13,50 % to the use of phosphorus as fertilizer; for the 28,50 % to the transport of the oranges from the warehouse to the distribution platform in the North of Italy; for the 21,9 % to the transport of the oranges from the field to the processing plant.
b) for the 16,7 % to the emissions in the air of 42 mg of PM < 2,5μ , which: the 30,6 % due to the transport of the oranges to the platform in the North of Italy; the 39 % comes from the citrus orchard life cycle associated to the production of the functional unit and in particular for the 64,1% to the watering process and for the 30,7 % to the dressing and weed killing processes; the 6,0 % associated to the processing phase and in particular for the 58,2 % to the conveyor belt and for the 26,5 % to the wood used for the footboards and for the crates; for the 25,9 % to the plant where the processing activity is done.

Resources

The damage to this category counts 2,45 * 10^{-5} pt and it is due:

- For the 48,1 % to the consumption of 39,1 gr of oil crude in ground and it depends for the: 52,3% to the transport of the oranges from the processing plant to the distribution platform in the North of Italy; 19,8 % to the transport of the oranges to the working warehouse; 17,1 % to the citrus orchard life cycle and in particularly for the 60,8 % to the irrigation processes and for the 21,5 % to the fertilizing ones.

Climate change

The damage in this case counts 1,94*10^{-5} pt and it is due:

- For the 70 % to the emissions in the air of 134 gr of CO_2 and it depends for the: 49,4 % to the transport of the oranges to the distribution platform in the North of Italy; 25,6 % to the citrus orchard life cycle, for the share associated to the production of 1 ton of oranges, and in particularly for the 79,4 % to the irrigating processes and for the 19,2 % to the transport of the oranges from the field to the processing plant;for -2,77 % to the processing plant and, in particularly, for the 40,1 % to the conveyor belt, 33,7 % to the polypropylene (PP) for the crates used for the oranges packing and transport systems, 28,0 % to the wood used for crates and for footboards and for -262 % to the wood recycle, which allows to obtain an avoided

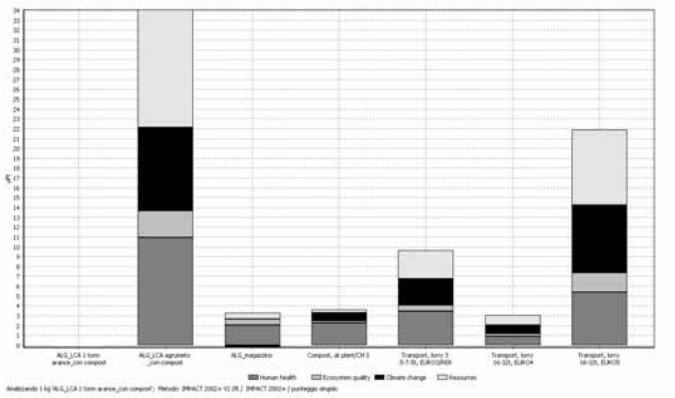

Figure 1: Oranges life cycle – single score evaluation per damage categories (impact 2002+)

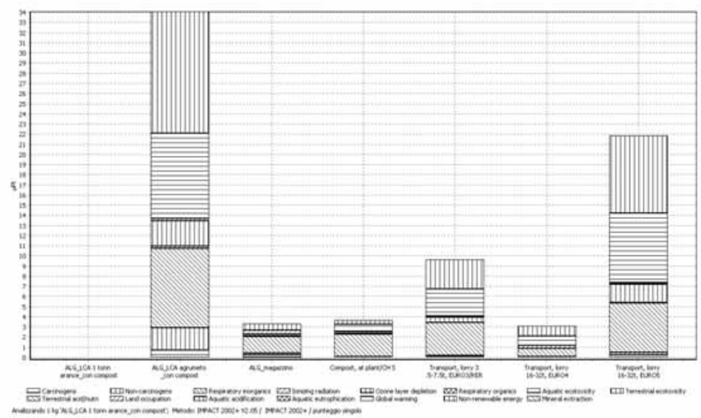

Figure 2: Oranges life cycle – single score evaluation per impact categories (impact 2002+)

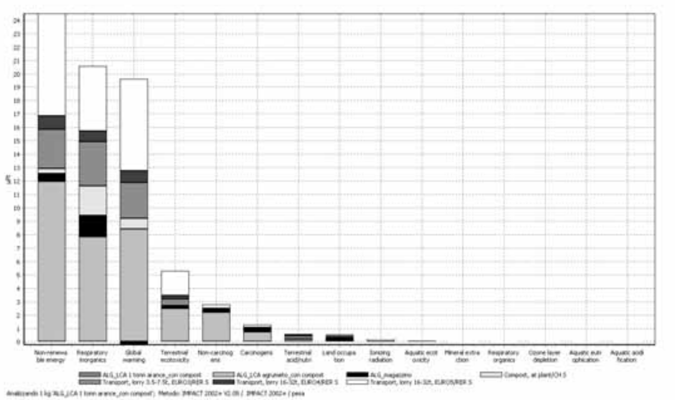

Figure 3: Oranges life cycle – Weighting per impact categories (Impact 2002+)

Table 1: Impacts Categories causing the highest damage

Impacts categories	Weighing (pt)	Characterization value	U.M.
Non renewable Energy	**2,45 E-5**	**3,72**	MJ primary
Respiratory Inorganics	**2,06 E-5**	**0,000208**	kg $PM_{2.5}$eq
Global Warming	**1,94 E-5**	**0,192**	kg CO_2eq

product as the particle board cement bounded at plant. This process allows in fact, to avoid the emission of 9,72 gr of CO_2 into the atmosphere.

Ecosystem Quality

The damage counts $6{,}52*10^{-6}$pt and it is due:

- for the 54,4% to the emissions into the soil of 1,04 mg di Zinc due: for the 45,6% to the citrus orchard, in particularly for the 58,8% to the irrigating process and for the 40,2% to the weeding and fertilizing treatments and for the 39,0% to the transport of the oranges to the distribution platform in the North of Italy.

As regards the impact categories, in table 1 it has been associated to each of them the weighing score and the characterization values (figure 3).

5. Conclusions

By assessing the oranges life cycle, it has resulted that their production is the most impacting phase, causing, in fact, almost half of the total damage. It depends on this phase being characterized by high consumptions of non-renewable resources, such as water -principally for the irrigating process- and all the raw materials associated to the various cultivation treatments. Based on these results, the following solutions are proposed, in order to reduce, as much as possible, the total damage associated to the citrus field life cycle and, consequently, to the oranges one: the water required for the field irrigating should be supplied by recycling it within a wetland plant; installing a photovoltaic plant to guarantee the electric energy consumption; adopt an organic farming system, rather than integrated, and so avoiding the environmental impacts due to the use of chemical products (fertilizers, pesticides and herbicides). These improvement proposals have not been detailed yet, since they are going to be object of another research, in order to understand if they are truly environmentally sustainable.

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