2 Life Cycle Assessment in the olive oil sector

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Abstract In this chapter the implementation of the Life Cycle Assessment (LCA) methodology in the specific sector of olive oil production is discussed. The olive oil industry is a significant productive sector in the European Union and the related production process is characterised by a variety of different practices and techniques for the agricultural production of olives and for their processing into olive oil. Depending on these differences, the olive oil production is associated with several adverse effects on the environment, both in the agricultural and olive oil production phases. As a consequence, using a tool such as LCA is becoming increasingly important for this type of industry. After an overview of the characteristics of the olive oil supply chain and its main environmental problems, the authors of this chapter provide a description of the international state-of-the-art of LCA implementation in this specific sector, also briefly describing other Life Cycle Thinking methodologies and tools suitable for the environmental assessment of this product (such as Simplified LCA, Footprint labels and Environmental Product Declarations). Then, the methodological problems connected with the application of LCA in the olive oil production sector are deeply analysed starting from a critical comparative analysis of the applicative LCA case studies in the olive oil production supply-chain. Finally, guidelines for the application of the LCA methodology in the olive oil production sector are proposed, in order to face and manage at best the methodological problems previously presented.

2.1 Introduction

Olive oil production is an important agri-industrial sector (both in terms of production and consumption) in many Mediterranean regions (IOC 2013; Vossen 2007). Furthermore, the olive grove and olive production are increasing yearly (FAOSTAT 2013) and, recently, the importance of olive oil is also growing, in new producing countries located in America, Africa and Australia (IOC 2013). However, on a global scale, most olive cultivation areas[1] can be found in Mediterranean Countries such as Spain (2,503,675 hectares), Italy (1,144,422 hectares), Tunisia (1,779,947 hectares), Greece (850,000 hectares), etc. (FAOSTAT 2013). The leader of international market is EU which produces over 70% of the world's olive oil. As concerns countries importing the product, the most important are USA, Japan, etc. With regard to exports, the most relevant are the main European Union Countries exporting over 440,000 tons of olive oil, followed by Tunisia, Syria, and others (Table 2.1).

Table 2.1 The olive oil market at international scale (the average values 2007/2008 - 2012/2013 olive crop six-year period)

Country	*Production (1,000 t)*	*Imports (1,000 t)*	*Exports (1,000 t)*	*Consumption (1,000 t)*
EU*	2,057.6	111.9	447.1	1,819.3
Spain	1,215.1	24.0	184.3	543.4
Italy	455.8	79.1	204.2	658.5
Greece	317.6	0.0	12.1	224.8
Portugal	58.4	1.4	41.0	80.9
France	5.3	5.4	1.6	108.7
Cyprus	4.9	0.0	0.0	5.5
Slovenia	0.5	0.1	0.1	1.9
Other EU countries	-	1.9	3.8	195.6
Tunisia	167.0	0.0	130.3	34.3
Syria	159.3	0.8	21.0	118.7
Turkey	149.2	0.0	22.9	124.0
Morocco	110.0	4.0	13.1	96.0
Algeria	47.4	0.2	0.0	47.0
Argentina	22.7	0.0	16.5	5.8
Jordan	20.8	3.6	1.5	20.7
Chile	15.4	0.8	6.2	10.7
Palestine	14.9	0.1	2.4	13.0

[1] data for the year 2011

Country	*Production (1,000 t)*	*Imports (1,000 t)*	*Exports (1,000 t)*	*Consumption (1,000 t)*
Lebanon	14.8	2.0	2.8	15.8
Libya	14.7	0.0	0.0	14.7
Australia	14.6	30.4	5.7	39.3
Israel	9.2	8.3	0.3	16.5
Albania	7.3	1.1	1.2	7.2
Egypt	5.8	1.9	1.4	6.5
Croatia	4.8	1.9	0.1	6.3
Iran	4.8	3.7	0.0	8.3
USA	4.3	270.2	3.7	271.3
Saudi Arabia	3.0	9.4	0.5	11.3
Montenegro	0.5	0.0	0.0	0.5
Other producing countries	15.0	3.0	5.5	13.1
Non-producing countries	-	250.8	-	250.8

*The import and export data of the EU Countries are reported without intra-Community trade
Source: Data (IOC 2013)

Despite the economic importance of this food product in many countries, olive oil production is associated with several adverse effects on the environment which cause resource depletion, land degradation, air emissions and waste generation. Impacts may vary significantly as a result of the practices and techniques employed in olive cultivation and olive oil production (Salomone and Ioppolo 2012) and Life Cycle Thinking approaches and assessment methods have increasingly been applied in order to better understand their role in a life cycle perspective.

In the following sections, these different practices and techniques with the relative environmental consequences are briefly described (Section 2.1.1). Then, a description of the international state-of-the-art of Life Cycle Thinking methodologies and tools, suitable for the environmental assessment of the product and implemented in this specific sector, is presented, with a specific focus on Life Cycle Assessment (LCA). Then, the methodological problems connected with the application of LCA in the olive oil production sector are deeply analysed starting from a critical comparative analysis of the applicative LCA case studies in the olive oil production supply-chain (Section 2.1.2). Finally, guidelines for the implementation of the LCA methodology in the olive oil production sector are proposed (Section 2.1.3), in order to deal with and manage at best the methodological problems above presented.

2.1.1 The olive oil supply chain: production processes, technologies, product characteristics and main environmental problems

As is well known a supply chain is the network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer (Christopher 1992). According to this definition, the olive oil supply chain can be briefly described, as follows (Niaounakis and Halvadakis 2006; Prosodol 2013; IOC 2013), using the different life cycle phases of the olive oil product: cultivation, olive oil production, by-product management, product transportation and distribution, consumption and waste management.

The ***cultivation phase*** includes the cultivation of olives using different treatments such as soil management, pruning, fertilisation, irrigation, pest treatment and harvesting. Each of these treatments[2] can be carried out in different ways depending on whether:

- the cultivation derives from centuries-old trees – traditional systems – or from new intensive plants (in the latter option, the supply chain study must include plant breeding and tree planting);
- the irrigation system uses the dry farming or the drip irrigation method;
- cultivation practices are conventional, organic or integrated, using different typologies of fertilisers and pest treatments;
- soil management, pruning and harvesting can be manual or mechanised.

Harvesting is a very important process, because changes in the acidity level of olives occur after harvest and other changes occur depending on the harvest methods: hand harvest is the best, but very expensive, while mechanical harvest, if properly done (avoiding the breaking of the fruit skin), can give good results. After harvest, olives are sent to olive oil mills, and processed, within 24 hours, in order to avoid fermentation phenomena.

Because the cultivation of olives can be carried out by means of various treatments, the environmental impacts can be very different in the various olive farming areas. However, by simplifying, three types of plantation can be considered: low-input traditional plantations (randomly planted and/or terrace planted ancient trees managed with few or no chemical inputs and high manual work input); intensified traditional plantations (they have the same characteristics of the first type together with: an increase in the tree density and in the weed control; soil management using artificial fertilisers and irrigation; the use of pesticides and mechanical harvesting); intensive modern plantations (high small tree density managed with a large use of mechanised systems and irrigation).

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[2] Some of these treatments and practices are managed similarly with other fruit cultivations (see chapter 6).

The low-input traditional plantations have the lowest environmental impact and, moreover, they play a role in safeguarding of biodiversity and landscape value. Instead, the other two types of plantations can give rise to various environmental problems (i.e. soil erosion, run off to water courses, degradation of habitats and landscapes and exploitation of scarce water resources) (Beaufoy 2000).

Much of the international olive production is transformed into olive oil. Different methods are used to extract oil from the olives and these processes create large volumes of liquid and solid wastes. The waste stream is highly hazardous to the environment and presents a number of treatment challenges for olive oil producers. The ***olive oil production phase*** includes two main phases: the preparation of a homogeneous paste and the oil extraction from olives.

First, the olives are classified and separated by quality, then washed in order to to remove pesticides, dirt, and impurities collected during harvesting (stems, leaves, twigs, etc.). Few olive oil mills do not wash olives that are processed "as it is" to overcome the problems connected with water consumption and the treatment of the polluted washing waters. This is often motivated with the fact that extra moisture can involve problems (extractability and polyphenol content is lower). However, these advantages should be cautiously compared with the disadvantages, since the pollution load of washing water demonstrates that olives need to be cleaned, otherwise pesticide and impurities remain on olives and then in the olive oil.

After washing, crushing (teraing of the flesh cells to facilitate the release of the oil from the vacuoles) and malaxing (mixing the paste allowing small oil droplets to combine into bigger ones) are essential steps.

The next step consists in separating the oil from the rest of the olive components: oil is extracted using a press or a decanter, by pressing (traditional or classical system) or centrifugal separator (continuous system), that can further use a three-phase or a two-phase decanter.

Traditional pressing (discontinuous process) is still in use in some small mills that use a hydraulic press, but it is a relatively obsolete technology mainly replaced with centrifugation systems that allow lower manufacturing costs, better oil quality and shorter storage time of olives before processing. This process generates a solid fraction (olive husk or olive pomace) and an emulsion containing the olive oil that is separated by decantation from the remaining wastewater.

Continuous centrifugation with a three-phase system, even if with a higher production capacity with respect to traditional pressing, has some disadvantages such as a greater water and energy consumption (due to the addition of warm water to dilute the olive paste). This process uses a three-phase decanter that generates a solid waste (olive husk or olive pomace), olive oil and wastewater.

Continuous centrifugation with a two-phase system allows to separate oil from olive paste without addition of water and this leads to elimination of the problem of vegetable water. In fact, the two-phase generates only olive oil and a semi-solid waste called olive wet husk or wet pomace (or two-phase olive mill waste).

Continuous centrifugation with a two and a half-phase system (also called modified system or water saving system) exists; being between a three-phase system and a two-phase one, it brings together the advantages of the two different systems (it requires the addition of a small amount of water and generates a solid fraction (Olive Wet Husk or olive wet pomace) that includes part of the vegetation water and a smaller quantity of olive mill wastewater.

Another innovative technology is the *oil extraction from de-stoned olives*. In the de-stoning process pits are removed before the kneading; some authors state that this process allows to improve the quality of the extra-virgin olive oil (better sensory qualities and shelf-life) (Del Caro et al. 2006; Pattara et al. 2010). However, other authors (Di Giovacchino et al. 2010) believe that this technology enables lower yields with a similar chemical sensory quality. Oil extraction from de-stoned olives can be made both with three-phase or two-phase system.

On average, all the above described techniques can produce around 200 kg of olive oil from 1 t of processed olives (Arvanitoyanni and Kassaveti 2008).

Therefore, as the average annual world production of olive oil in the 2007/2008-2012/2013 olive crop six-year period is equal to 2,862,800 t (IOC 2013), on the basis of data available in the literature, it is possible to estimate that, on average in a year, the olive oil industry needs 572,560,000-1,674,738,000 kWh of energy and 1,431,400-16,045,994 m^3 of water, generating 5,725,600-8,588,400 t of solid waste and 8,588,400-17,176,800 t of wastewater (estimation from Arvanitoyanni and Kassaveti 2008).

The designation of *virgin olive oil* is solely recognised to the olive oil obtained from the fruit of the olive tree by mechanical or other physical means under condition, particularly thermal conditions, that do not lead to alterations in the oil, and which has not undergone any treatment other than washing, decantation, centrifugation and filtration, excluding oils obtained using solvents or re-esterification processes and of any mixture with oils of other kinds (Reg. EEC 702/2007 and Reg. EEC 640/2008). In particular, in accordance with the Council Regulation (EC) 1513/2001 *virgin olive oils* are classified in:

- *extra-virgin olive oil*, that is a higher quality olive oil with no more than 0.8 grams per 100 grams of free acidity (expressed as oleic acid), and a superior taste (fruitiness and no sensory defect). It must be produced entirely by mechanical means without the use of any solvents, and under temperatures that will not degrade the oil (less than 30°C);
- *virgin olive oil,* that has no more than 2 grams per 100 grams of free acidity and a good taste;
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- *lampante olive oil* that is virgin olive oil having a free acidity, in terms of oleic acid, of more than 2 g per 100 g, and/or the other characteristics of which comply with those laid down for this category.

Other classifications are related to the definition of *olive oil*, distinguishing:

- *refined olive oil*, obtained by the refining of virgin olive oil using methods which do not lead to alterations in the initial glyceridic structure; it has no more than 0.3 grams per 100 grams of free acidity,
- *olive oil*, is a blend of refined oil and virgin oil (excluding the lampante virgin oil) fit for consumption as they are. It has no more than 1 gram per 100 grams of free acidity,
- *olive-pomace oil*, obtained by treating olive pomace with solvents or other physical treatments. This oil can be sold as: *crude olive-pomace oil* which is intended for refining (then designated for human consumption) or for technical use, and *refined olive pomace oil* obtained from crude olive pomace oil by refining methods allowing the obtainment of an oil with no more than 0.3 grams per 100 grams of free acidity.

In the olive oil production phase the packaging process is also included even if olive oil is often sold unbottled (to final consumers or to national or multinational bottling companies) and only few mills directly bottle olive oil with an own label. Olive oil is generally bottled in stainless steel containers or better in glass bottles (in order to better preserve stability of virgin olive oil), although there are cases of use of innovative packaging - e.g. bottles in polyethylene terephthalate (PET), 100% recyclable (Salomone et al. 2013).

In the ***by-product management*** phase, two methods are used to extract pomace oil. Olive-pomace oil obtained from two-phase processing, with a moisture content close to 70%, is physically extracted by centrifugation. The process also produces a residual water solution of high commercial value due to the presence of mineral salts, sugars and polyphenols. To extract pomace oil from the traditional and three-phase production methods, solvents are used. The olive pomace is mixed with the solvent hexane, that dissolves any residual oil. The exhausted pomace is then separated from the oil and hexane solution (called miscella) by filtration. Any hexane residues in the solid pomace are removed by means of a 'desolventiser', which evaporates the solvent, which is then captured for reuse. The oil and hexane solution is distilled, allowing the hexane to be recovered and reused, whilst the solvent-free oil goes through further processing such as refining. Solid wastes from olive oil mills are also referred to as "olive cake" (depleted olive pomace) and liquid waste streams are termed olive-mill wastewater.

In recent years, the *by-product management* is considered a strategic phase in the olive oil supply chain, because each of the different olive oil production methods creates different amounts and types of by-products, all of which are potentially hazardous to the environment. Therefore, the above mentioned environmental problems have given rise to a series of studies for the development of methods for the treatment and valorisation of olive mill wastewater (Demerche et al. 2013; Kapellakis et al. 2008; Stamatelatou et al. 2012) and olive stones from de-pitted virgin olive oil (Pattara et al. 2010).

In particular, the olive oil mill wastes have a great impact on land and water environments due to their high phytotoxicity (Roig et al. 2006) and their management is one of the main problems of the olive oil industry. Many management options have been proposed for their treatment, disposal or valorisation (Vlyssides et al. 2004; Niaounakis and Halvadakis 2006; Roig et al. 2006):

- Olive Mill Wastewaters (OMW), deriving from traditional pressing and from three-phase system, are the main pollutant mill waste. These are constituted by vegetable water of the olives and the water used in the oil extraction and their chemical composition is variable depending on olive varieties, growing practices, harvesting period and oil extraction technology. In any case, it is greatly pollutant due to the presence of organic compounds (organic acids, lipids, alcohols and polyphenols), even if they also contain valuable substances such as nutrients (especially potassium). Untreated olive mill wastewater is a major ecological issue for olive oil producing countries due to its highly toxic organic loads. Olive mill wastewater can lead to serious environmental damage, ranging from coloring natural waters, altered soil quality, phytotoxicity, and odor nuisance. Traditional olive oil processing methods are estimated to produce between 400 and 600 litres of *alpechin* (*OMW* - olive mill wastewater) for each ton of processed olives. Olive-mill wastewater levels from three-phase processes are much higher, producing between 800 and 1,000 litres of OMW for each ton of processed olives. Virtually no wastewater is produced by the two phase process, although its *wet pomace* waste streams tend to have high liquid contents which remain costly to treat. The olive mill wastewater is composed essentially of water (80-83%), organic compounds (mainly phenols, polyphenols and tannins) that account for a further 15-18% of wastewater content, and inorganic elements (such as potassium salts and phosphates) that make up the remaining 2%. These proportions can vary depending on factors related to climatic and soil conditions, farm management, harvesting methods and oil extraction processes. The presence of proteins, minerals and polysaccharides in *OMW* means that olive mill wastewater has potential for use as a fertiliser and in irrigation. However, reuse opportunities are restricted by the abundance of phenolic compounds that are both antimicrobial and phytotoxic. These phenols are difficult to purify and do not respond well to conventional degradation using bacterial based techniques. Olive oil mill polluting loads are therefore significant, revealing levels of both BOD_5 (biological oxygen demand in 5 days) and COD (chemical oxygen demand) between 20,000 and 35,000 milligrams per litre. This represents a notably large organic matter load compared to standard municipal wastewater, which exhibit levels between 400 and 800 milligrams per litre. Anaerobic digestion of *alpechin* results in only 80 to 90% COD removal and this treatment remains insufficient to permit olive mill wastewater effluent to be discharged back into the environment. Discharging unsafe olive mill wastewater back into natural water systems can result in a rapid rise in number of microorganisms. These microorganisms consume large amounts of dissolved oxygen in the water and so reduce the share available for other living organisms. This could quickly offset the equilibrium of an entire ecosystem.

Further concerns are caused by the high concentrations of phosphorus in olive mill wastewater, since if released into water courses this can encourage and accelerate the growth of algae. Knock on impacts include eutrophication which can destroy the ecological balance in both ground and surface water systems. Phosphorous remains difficult to degrade and tends to be dispersed only in small amounts via deposits through food chains (plant - invertebrates – fish – birds, etc.). The presence of large quantities of phosphorous nutrients in olive mill wastewater provides a medium for pathogens to multiply and infect waters. This can have severe consequences for local aquatic life, as well as humans and animals that come into contact with the water. Several other environmental problems can be caused by olive-mill wastewater. These include: lipids in the olive mill wastewater producing an impenetrable film on the surface of rivers, their banks and surrounding farmland.
At a glance, the most common treatment methods of OMW are:

a) evaporation in storage ponds in the open – this method produces sludge that may be disposed in landfill sites or used as fertiliser in agriculture (after a composting process with other agricultural by-products) or as heat source;
b) direct application on soil – this is a positive valorisation method of OMW considering its high nutrient content and its high antimicrobial capacity, but it causes also negative effects on soil associated with its high mineral salt content, low pH and presence of polyphenols. In Italy and in some other countries, land spreading of wastes arising from olive processing is specifically regulated by law (DM MIPAF 6 July 2005). In other European countries every state regulates with autonomous laws rules regarding OMW what about the rest of Europe??????;
c) co-composting – this method refers to the co-composting of OMW with olive pomace or olive wet pomace; it allows the return of nutrients to cropland and avoid the negative effects previously cited when OMW is directly applied to soil. (Cappelletti and Nicoletti 2006; Salomone and Ioppolo 2012);
d) extraction of valuable organic compounds - the recovery of high value compounds (phenolic compounds, squalene and tocopherols, triterpenes, pectins and oligosaccharides, mannitol, polymerin) or the utilisation of OMW as raw matter for new products is a particularly attractive way to reuse it, always that the recovery process is of economic and practical interest. Fernández-Bolaños et al. 2006.

- Olive Husk (OH), deriving from traditional pressing and from three-phase system, is usually sent to oil factories (oil-husk extraction mills) that, after a drying process, extract oil with specific solvents (traditionally hexane). This treatment process produces oil and a solid waste called *exhausted olive husk* used as fuel since the dried OH presents a high calorific power.
- Olive Wet Husk (OWH), deriving from the two-phase system. In this case, olive vegetation waters are included in the OWH and this cause a high moisture content that creates great difficulties to treat in oil factories as for the OH

(mainly a higher energy demand for the drying process causing higher costs). For this reason there are other methods for the treatment of OWH and the most common are:

1. direct application on soil – due to its high potassium concentration and its low economic value it can be directly applied to soil in land near the production site, but this practice could cause negative effect on soil even if it is less phytotoxic than wastewaters (Cichelli and Cappelletti 2007);
2. composting (with or without de-stoning process to obtain biomass for heat or electricity) – this method consists in the co-composting of OWH with other agricultural wastes (straw, leaves, etc.) or with manure used as bulking agents. The compost obtained has a good degree of humification, no phytotoxic effect and a good amount of mineral nutrients (Cappelletti and Nicoletti 2006; Russo et al. 2008).

The ***transportation and distribution phase*** includes all the transport activities, related to raw materials, by-products, wastes depending on production capacity and localisation of firms, and distribution of the product in the sell market at a local, regional, national or international level, depending on the strategy and production capacity of the firm that bottles olive oil in glass or tin containers, PET bottles with their labels. As the average annual world consumption of olive oil in the 2007/2008-2012/2013 olive crop six-year period is equal to 2,862,800 t (IOC 2013), assuming that only containers capable of holding 1 kg of olive oil are used, the packages in circulation could be more than 2,860,000,000 per year. Transport activities can occur also elsewhere in the life cycle (other than those already mentioned), either between any two subsequent life-cycle stages or within a given stage, depending on the site-specific means of processing and the level of supply-chain integration.

The ***consumer phase***, in the case of the olive oil, is certainly not significant in a life cycle perspective, considering that the product consumption doesn't need further preparations or treatments. Table 2.1 shows that consumption of olive oil is quite widespread at international scale in countries such as Italy, Spain, USA, Greece, Turkey, Syria etc.

Finally, the ***waste management phase*** (end of life) includes the procedures for treatment of the bottles and waste of packaging (cardboard boxes, etc.). This phase can also have great impacts on the environment depending on the chosen method of waste management (for example, reuse, recycling, landfilling, etc).

The phases of the olive oil supply chain with the related main environmental impacts are synthetically represented in Fig. 2.1. .

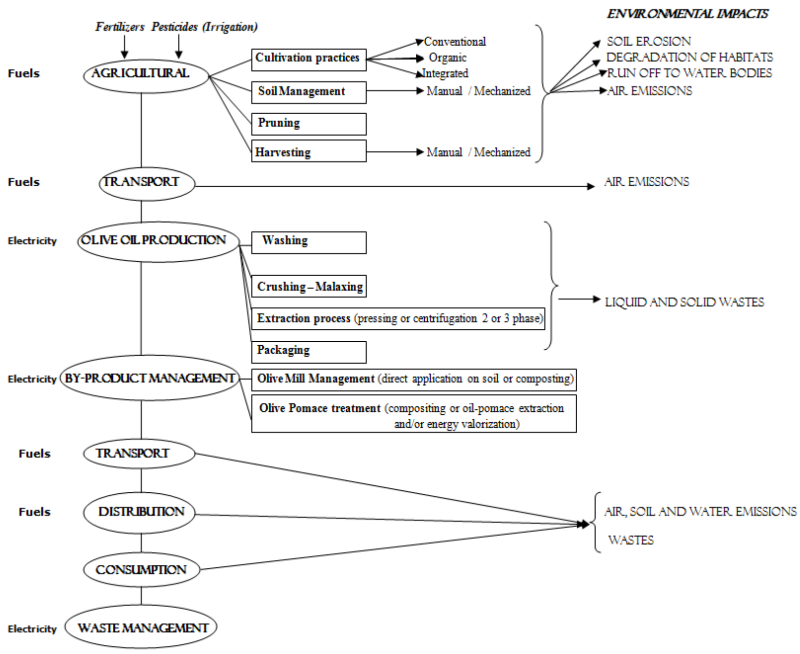

Fig. 2.1 The olive oil supply chain and main environmental impacts

As far as the materials and energy balance related to the oil production is concerned, it is possible to highlight that the production (agricultural and industrial phases) of 1kg of olive oil (double pressed) involves the consumption of 0.0264 kg of fertilizers (N_2, P_2O_5, K_2O), 0. 019 kg of pesticides, 0.00855 kg of fuel, 0.243 kg of lube oil, and 0.359 kWh of electrical energy (Nicoletti and Notarnicola 2000).

2.2 Life Cycle Thinking approaches in the olive oil production sector: state-of-the-art of the international practices

As exhaustively reported in chapter 1, the growing awareness on food sustainability is driving an increase in research activities in the agri-food sector and, among these studies, over the last fifteen years or more, numerous Life Cycle Thinking (LCT) approaches have been carried out (mainly Life Cycle Assessment studies) evaluating food products and processes in order to identify and pursue sustainable food production and consumption systems.

The specific sector of olive and olive oil supply-chain has been investigated by several LCT studies since 2000. A critical analysis and state of the art of LCA studies applied in the olive oil sector was, firstly, conducted in 2008 (Salomone et al. 2008) and then updated in 2010 (Salomone et al. 2010a), but containing only a comparative analysis of Italian studies, with the aim of highlighting features and/or differences of the fundamental aspects of Italian LCA studies; the first review included 13 Italian LCA case studies, while the second one counted for 23 case studies. On the contrary, the literature review presented in this paragraph is a wider and deeper analysis in respect to the previous ones, because it includes:

- International case studies, not only the Italian ones;
- Life Cycle Thinking tools, not only the LCA ones;
- “Olive industry” case studies, not only the olive oil ones.

In particular, this literature review includes LCA studies that directly or indirectly refer to the wider term of “olive industry”, therefore including applications not only to olive oil production, but also to olives in general (for oil or table use), to olive oil mill waste treatment and valorisation, and to table olive and olive oil packaging. The review refers to book chapters and articles published in international and Italian scientific journals and conference proceedings from 2000 to 2013; grey literature or other published papers could be missing.

In Table 2.2 the identified articles are listed, specifying the LCT tool used for the analysis and the product being investigated: 42 used LCA, 7 applied both LCA and Life Cycle Costing (LCC) or another kind of economic analysis, 2 implemented a Simplified LCA (S-LCA), 9 deal with environmental Footprints (Carbon, Water or Ecological Footprint) or energy balance or analysis, and carbon balance, 10 are EPDs (Environmental Product Declarations) or papers reporting on EPDs, and 2 reports on an integrated use of LCA and Multi Criteria Analysis (MCA).

Table 2.2 Articles reporting on the implementation of LCT tools in the olive industry

Reference	*LCA*	*Other tools*	*Product*
Nicoletti and Notarnicola 2000	✓		Olive oil
Raggi et al. 2000		S-LCA	Olive husk
Nicoletti et al. 2001	✓		Olive and sunflower seed oil
Mansueti and Raggi 2002	✓		Olive husk
Salomone R. 2002	✓		Olive oil
Abeliotis 2003		S-LCA	Olive oil
Notarnicola et al. 2003	✓	LCC	Olive oil
Notarnicola et al. 2004	✓	LCC	Olive oil
Romani et al. 2004	✓		Olive oil
Cecchini et al. 2005	✓		Olive oil
De Gennaro et al. 2005	✓		Olive oil

Reference	*LCA*	*Other tools*	*Product*
Olivieri et al. 2005a	✓		Olive oil
Olivieri et al. 2005b	✓		Olives
Nicoletti et al. 2007a	✓		Table olives
Nicoletti et al. 2007b	✓		Table olives packaging
Olivieri et al. 2007a	✓		Olive oil
Olivieri et al. 2007b	✓		Olive oil
Avraamides and Fatta 2008	✓		Olive oil
Cappelletti et al 2008	✓		Table olives
Cini et al. 2008	✓		Olive oil
Guzman and Alonso 2008		EB	Olive oil
Olivieri et al. 2008	✓		Olive oil
Russo et al. 2008	✓		Olive husk
Salomone 2008	✓	Review	Olive oil
Fiore et al. 2009	✓		Olive oil
Russo et al. 2009	✓		Olive oil
Salomone et al. 2009	✓		Olive oil
Scotti et al. 2009		EF	Olive oil
Cappelletti et al. 2010	✓		Table olives
Cavallaro and Salomone 2010	✓	MCA	Olive oil
Olivieri et al. 2010a	✓		Olive oil Mill Wastewater
Olivieri et al. 2010b	✓		Olive oil Mill Wastewater
Polo et al. 2010	✓		Olive oil
Roselli et al. 2010	✓	LCC	Olive oil
Russo et al. 2010	✓		Table olives
Salomone et al. 2010a	✓		Olive oil
Salomone et al. 2010b	✓	Review	Olive oil
Cappelletti et al. 2011	✓		Table olives
Christodoulopoulou et al. 2011	✓		Olive oil
ECOIL 2011	✓		Olive oil
Intini et al. 2011	✓	CF	Olive oil Mill waste
Nicoletti et al. 2011	✓	EPD	Olive oil
Özilgena and Sorgüvenb 2011		EA	Soybean, sunflower and olive oil
Recchia et al. 2011	✓	MCA	Olive oil
Salmoral et al. 2011		WF	Olive oil
Apolio 2012		EPD	Olive oil
Assoproli 2012		EPD	Olive oil
Busset et al. 2012	✓		Olive oil
Cappelletti et al. 2012	✓	EPD	Olive oil
Carvalho et al. 2012	✓	LCC	Olive oil

Reference	LCA	Other tools	Product
De Cecco 2012		EPD	Olive oil
De Gennaro et al. 2012	✓	LCC	Olives
Farmers Groups 2012		EPD	Olive oil
Intini et al. 2012	✓		Olive husk
Lucchetti et al. 2012		CF	Olive oil
Monini 2012a		EPD	Olive oil
Monini 2012b		EPD	Olive oil
Monini 2012c		EPD	Olive oil
Monini 2012d		EPD	Olive oil
Neri et al. 2012	✓	EA	Olive oil
Russo et al. 2012	✓		Table olives
Salomone and Ioppolo 2012	✓		Olive oil
Testa et al. 2012	✓		Olive oil
Chatzisymeon et al. 2013	✓		Olive oil Mill Wastewater
El Hanandeh 2013	✓		Olive oil Mill Waste
Iraldo et al. 2013	✓		Olive oil
Kalogerakisa et al. 2013	✓		Olive Mill Waste
Nardino et al. 2013		CB	Olives
Notarnicola et al. 2013	✓		Olive oil
Palese et al. 2013		SM	Olives
Pergola et al. 2013	✓	EA	Olives
Salomone et al. 2013	✓	S-LCA	Olive oil packaging

CB = Carbon Balance; CF = Carbon Footprint; EA = Energy Analysis; EB = Energy Balance; EF = Ecological Footprint; EPD = Environmental Product Declaration; LCC = Life Cycle Costing; MCA = Multi Criteria Analysis; S-LCA = Simplified LCA; SM = Sustainable model (economic and environmental analysis); WF = Water Footprint.

In the following, the state-of-the-art analysis of literature on Life Cycle Thinking studies implemented in the olive and olive oil production is presented, discerning between scientific articles including only the LCA methodology and articles concerning other LCT tools (LCC, S-LCA, Footprint label, EPD, etc.).

2.2.1 Life Cycle Assessment

The literature review shows that the most used LCA analysis applied in the olive oil sector present a comparative nature. Indeed, the first LCA study, applied in this sector, dates back to 2000 (Nicoletti and Notarnicola 2000) and focuses on the comparison between irrigated and dry olive cultivation systems together with different olive oil extraction techniques. The comparison allows the evaluation of six different systems, obtained from the combinations of two agricultural practices (dry and wet systems) and three extraction processes (single pressure, double pressure and centrifugation). This analysis structure, differently combining various systems and methods, was lately applied in other papers (such as De Gennaro et al. 2005; Salomone et al. 2010a; Salomone and Ioppolo 2012; Busset et al. 2012), also adding alternative treatments of olive oil mill waste, thus offering an articulated comparative LCA of very different olive oil production scenarios. In particular, De Gennaro et al. (2005), combine various processes of the olive oil production chain combining different oil extraction methods of extra virgin olive oil and different disposal and/or reuse treatments of pomace and other olive oil mill waste. The analysis indicates as the most eco-compatible production chain the one that uses a continuous two phase transformation and the pomace treatment for the production of fuel, while the least eco-compatible system is the system entailing three phase continuous production, composting of the pomace and spreading on ground of the oil mill waste water. In Salomone et al. (2010a), and Salomone and Ioppolo (2012), comparisons of eight different scenarios including different combination of cultivation practices, oil extraction methods and olive oil mill waste treatment are presented. The analysis highlights a higher environmental load for conventional scenarios (except for impact categories associated to land use), an important environmental load associated with some sub-processes (such as fertilisation, use of pesticides and combustion of exhausted pomace), the higher environmental contribution of the sub-process of co-composting of Olive Wet Pomace (OWP) with manure on fields rather than the co-composting of Olive Mill Wastewater (OMW) and OWP with the composter machines, and a significant positive contribution (in terms of environmental credits for avoided production) associated with the use of by-products such as fuels or fertilisers. Busset et al. (2012) defined all the scenarios for olive oil production in France based on the different olive production techniques, the different extraction processes and the different waste. Another paper with a similar structure is Cavallaro and Salomone (2010) but with new insights, because the LCA was implemented with MCA (see Section 2.2.6).

A different kind of comparative LCA study is dated 2001 (Nicoletti et al. 2001), presenting an evaluation of olive oil and sunflower seed oil. The results indicate that olive oil is more eco-compatible for all categories except for land use. The most impacting phase is the agricultural phase for both systems (the main differences in this phase occur for the ODP category caused by Halon emission due to the production of pesticides from the sunflower cultivation). Concerning the industrial phase, higher impacts are connected with sunflower oil due to VOC emissions occurring during sunflower oil chemical extraction.Another scientific article presents a comparison of olive oil with other kind of vegetable oil is Özilgena and Sorgüvenb (2011), but it does not use a LCA study, but Energy Analysis (see Section 2.2.4).

Other comparative LCA studies focus on specific life cycle step. For example, Russo et al. (2009) focus on the comparison of two processes of production of extra virgin olive oil using whole or de-stoned olives. The two processes present a similar environmental performance even if the process in which de-stoned olives are used has lower impact: the real advantage of the de-pitting process is to obtain fragments of olive stone, which is an important by product (very appreciated as fuel) both from an environmental and economic point of view. Similarly, Romani et al. (2004) focus on specific life cycle steps but report on two diverse LCA applications: comparison of organic and conventional virgin oil production, and comparison of two different applications for Olive Oil Mill Wastewater. The comparison of organic and conventional olive oil production is an aspect that was already investigated with integrations of LCA and LCC methodologies (see Section 2.2.2), and other studies have, then, differently performed to compare this cultivation practices. Indeed, Cecchini et al. (2005) compared integrated, organic and conventional production of olive oil in Southern (Italy) and Neri et al. (2012) compared two organic and conventional farms in the central part of Italy, highlighting higher impacts for the agricultural phase in both case studies: in the organic production, impacts are related to a huge amount of fuel consumption (because of the use of old and low-efficiency machineries), whereas in conventional one, the main impacting input is the use of chemicals.

Olivieri et al. (2005a; 2005b) apply LCA with a particular focus on the olives cultivation phase, both for the conventional and organic farming, with the aim of quantifying numerically the environmental damage of the olives cultivation process and to estimate the opportunities to reduce the impacts by the comparison with the organic olives cultivation (sensitivity analysis). Generally, these studies highlighted higher impacts for conventional cultivation (except for the land use impact category).The other LCA presented in Romani et al. (2004), entailing the comparison of different wastewater treatment, falls into another widespread kind of LCA analysis that refers to waste treatment. Indeed, in 2002 a first LCA application not focused on olive oil, but on one of the main olive oil mill waste (olive husk or olive pomace) was performed (Mansueti and Raggi 2002). In particular, this study reports the results of a comparative LCA between power generation from olive husk combustion and from conventional technologies, highlighting that power generation from olive husk combustion (dark bars), for this specific case-study, only deals with two kinds of impact categories: respiratory inorganic effects and acidification/eutrophication. As far as climate change is concerned, the olive husk combustion process has virtually no effect, since, as it is well known, CO_2 from biomass is not considered responsible for global warming.

After this paper, other LCA applications specifically focused on olive oil mill waste were published and/or presented, such as the following cases:

- in Romani et al. (2004) a comparison of two different uses for Olive Mill Wastewater (the fertilisation-irrigation and the optimised purified procedures able to recover higher quantities of polyphenols in view of possible future industrial application) is presented, and the lower environmental loads for the treatment allowing polyphenols recovery are highlighted;

- in Russo et al. (2008), an analysis of the environmental advantage deriving from the use of olive pit as fuel (by combustion in the furnaces commonly fed by using wood pellets or de-oiled pomace), comparing its environmental impact with that generated by the recovery of de-oiled pomace and the production of wood pellets, is performed. The results showed that the recovery of olive pit offers environmental advantages with respect to other alternative fuels. This depends fundamentally on the higher net calorific value of the pit fuel and also on its simple recovery method (at the beginning of the process of olive-oil extraction);
- in Olivieri et al. (2010a; 2010b), an LCA study applied to a new integrated technology for Olive Oil Mill Wastewater (OMW) treatment and polyphenols recovery from biphasic olive mill is presented. This method 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" (e.g. phytotherapy, cosmetics). The results of sensitivity analysis show that the LCA of this process is less impacting for an overall percentage of 57% respect to traditional process. The recovery of polyphenols from olive oil wastewater is important to add value to this waste as these substances can be an important source of new antioxidant products in the "novel food". Moreover, the recovery of polyphenols helps to avoid phytotoxicity in soil;
- in Intini et al. (2012), a LCA was carried out in order to compare the environmental performance of using de-oiled pomace and waste wood as fuel. Only the global warming potential has been calculated and compared with that of a plant for energy production that uses refuse derived fuel (RDF) and that of one that uses coal. The LCA shows the important environmental advantages of biomass utilisation in terms of greenhouse gas emissions reduction;
- in Chatzisymeon et al. (2013), the LCA methodology was utilised to evaluate three different advanced oxidation processes for olive oil mill wastewater treatment (UV heterogeneous photocatalysis – UV/TiO_2; wet air oxidation – WAO; and electrochemical oxidation - EO). Both EO and WAO can be competitive processes in terms of COD, TPh and colour removal. EO was found to be a more environmentally friendly technique as it yields lower total environmental impacts, including CO_2 emissions to atmosphere. The environmental impacts of all three treatments show that human health is primarily affected followed by impacts onto resources depletion. Overall, it was found that the environmental sustainability of these treatments is strongly related to their energy requirements and that their total environmental impacts decline according to the following order: $UV/TiO_2 > WAO > EO$;
- in El Hanandeh (2013), LCA was used to analyse the carbon emission reduction potential of utilising olive husk as a feedstock in a mobile pyrolysis unit. Four scenarios, based on different combinations of pyrolysis technologies (slow versus fast) and end-use of products (land application versus energy utilisation), are compared and the results show that all scenarios result in significant greenhouse gas emission savings;

- in Kalogerakisa et al. (2013), an LCA of the extraction of compounds, such as hydroxytyrosol and tyrosol as well as total phenols (TPh), from real Olive Oil Mill Wastewater (OMW) was performed, in order to provide the best available and most sustainable extraction technique using ethyl acetate, chloroform/isopropyl alcohol and diethyl ether. The use of ethyl acetate yields low environmental impacts and high antioxidant recovery performance and, therefore, it is assumed as the best option, both from an environmental and technical point of view, while chloroform/isopropyl alcohol mixture was found to pose detrimental effects onto the ecosystem, human health and fossil resources.

Another kind of LCA study in this sector relates to the analysis of the main life cycle phases. Indeed, in 2002 a paper presenting a cradle-to-gate analysis was presented (Salomone 2002), including: cultivation of olives, olive oil production, olive husk treatment and transport between these treatment phases. This is the first study that includes pomace treatment in the LCA analysis of the product "olive oil". The motivation is to avoid allocation, as suggested by ISO 14044 (at the time of the research ISO 14041), expanding the system in order to include also the treatment of this by-product of olive oil production. After this, other papers studied the olive oil production chain including the reuse of by-products and waste, such as the above mentioned comparative LCAs of different olive oil production scenarios (Salomone et al. 2010a; Salomone and Ioppolo 2012), but in these cases the motivation was mainly connected with a vision of integrated environmental management of the whole olive oil production chain (thus including by-products treatment and valorisation). Also in Cini et al. (2008) LCA was used in order to evaluate the environmental impact of olive oil production considering different possibilities for the by-product reuses, but (similarly to De Gennaro et al. 2005) the paper does not include the cultivation step, cut it just considers the extraction process of olive oil, with different methods: extraction process with oil production and pomace treated as waste; extraction process with oil production and pomace used as fertiliser; extraction process with oil and pomace stone productions; extraction process with oil and pomace stone productions, using pomace residue as fertiliser.

In 2007, table olives production also started to be investigated, mainly because of the growing interest for this specific sector caused by the increase of their cultivation and processing activities, as well as the relevant amount of wastes generated by the connected processing industries. Different papers deeply analysed this particular kind of production and its various aspects: green olive cultivation and olive processing using the Spanish-style method (Nicoletti et al. 2007a; Cappelletti et al. 2010); black olive cultivation and olive processing using the Californian-style method (Cappelletti et al. 2008); comparison of three different methods used for processing ripe table olives – two different methods of the California style and the Spanish style method (Russo et al. 2010; Russo et al. 2012); a comparison of the different packaging systems (Nicoletti et al. 2007b); and a study (Cappelletti et al. 2011) that focuses on the production processes, the characteristics of wastewaters, and the pollution prevention technologies (in this case the LCA results underlined that the eutrophication is a very important impact for the table olives processing industries, and it derives from the pollution of the wastewater).

Some LCA applications in the olive oil sector relate to the analysis of olive oil production in specific geographic areas, such as:

- Avraamides and Fatta (2008) – LCA has been used to evaluate the consumption of raw materials and emissions of pollutants from olive oil production in Cyprus (Greece), and to identify the processes causing the most significant environmental burdens. The interpretation results were organised in an interesting classification of the individual processes in priority categories according to their potential optimisation: fertilisation and oil extraction processes should be considered as priority 1 processes, irrigation and pruning are classified in priority 2, pest control and soil management in priority 3 and tree planting, collection and transportation of olives to the processing unit (as their contribution to all environmental flows considered was less than 0.5%) of priority 4;
- Fiore et al. (2009) – in this paper results of an LCA application to the Sicilian (Italy) olive oil production, obtained from olives cultivated by an intensive managing system are described. The study highlights the environmental burden deriving from the agricultural phase and also the packaging phase that involves environmental impact due to the glass bottle production;
- Christodoulopoulou et al. (2011) - a comprehensive LCA was carried out on an olive oil of extra virgin quality, produced from 487 olive groves by three groups of 68 olive growers in south Greece. The first goal of the study is to assess the environmental performance of olive oil in order to use it for an Environmental Product Declaration (EPD) according to PCR 21537 of Environdec. A second goal is to use the LCA as a starting point for the continuous improvement procedure with regard to the environment, by identifying the areas with the most significant impacts, and by taking measures for their control;
- Busset et al. (2012) - a LCA study of the French olive oil production sector is presented: it was elaborated partly in order to reduce the carbon footprint and to optimise waste management of the olive oil sector in SUDOE area (Spain, Portugal and France). First results have permitted to define all the scenarios for olive oil production in France based on the different olive production techniques (with or without irrigation, mechanical or not, organic or not), the different extraction processes (pressing, centrifugation two phases or centrifugation three phases) and the different waste management schemes (incineration or spreading). Expected results are the comparison of all the scenarios in order to identify parameters that influence environmental consequences of olive oil production;
- Salomone and Ioppolo (2012) - the LCA methodology was applied to investigate the olive oil sector and identify useful information for taking strategic de-

cisions aimed at the improvement and optimisation of a local olive oil chain in the province of Messina (Italy), directly involving a sample of companies of the local association of oil producers;

- Notarnicola et al. (2013), analysed the cultivation phase of olives for the production of olive oil performed in 63 farms in the northern area of the city of Bari in Puglia (Italy) with the aim of assessing the variability of LCA results. This is one of the few papers which analyses on the same inventory more than sixty data sets. The results indicate a large variability within the management methods of the olive orchard with agronomical practices differing from producer to producer (even if from the same area). This is reflected in the high variability of the inventory and impact assessment results.

Other interesting applications of the LCA methodology within the field of olive oil production, is its use for supporting the definition of environmental management strategies and integration of tools. Into this category of studies, three cases could be included:

- the first one is the case reported in different papers discussing integrated environment-quality-HACCP systems aimed to realise useful guidelines useful for the acquisition of a territory product mark (Olivieri et al. 2007a; Olivieri et al. 2007b; Olivieri et al. 2008). LCA has been used to characterise environmental critical states in cultivation and production of virgin oil; the most important identified problems are the use of fertilisers, the use of pesticides for olive fly-capture and land-use in the conventional olives cultivation;
- the second one is the case of a study specifically focused on the design of a model of Product-Oriented Environmental Management System (POEMS) for agri-food companies (Salomone et al. 2013) that include the use of LCA methodology for the product orientation of Integrated Management Systems; one of the case studies reported is the comparison of two different packaging systems of extra-virgin olive oil: glass vs PET bottle. The overall comparison highlights higher scores for the glass bottle system compared to the PET bottle one, except for fossil depletion category in which the higher score is linked to the PET bottle system, caused by PET production;
- the third one is a LCA applied to the production of extra virgin olive oil in the Val di Cornia, Tuscany –Italy (Testa et al. 2012). The LCA study should support the experimental implementation of a system of environmental qualification of product, managed locally, which combines the features of eco-labels, type I and III. The agricultural phase is the most impactful of all categories, in particular, due to acidification, eutrophication and water consumption. The major impacts result from the production of pesticides. However, the use of pruning residues as fertiliser and for domestic heating brings significant benefits for certain impact categories of impact. In the extraction phase, olive mill waste water recovery as fertiliser leads to a reduction in water consumption, eutrophication and global warming.

Another application of LCA presenting newly insights is Salomone et al. 2009 in which a comparison between a conventional extra-virgin olive oil and a high quality extra virgin olive oil with characteristic of excellence is presented. The new element consists of an attempt of integration between environmental impacts and quality characteristic of the product in the LCA methodology by inserting a impact category called "cardiovascular risk" defined on the basis of the contribution that the phenols, contained in olive oil, have in increasing the HDL-cholesterol (which helps reducing the cardiovascular risks); the aim of the study is to match the potential environmental impacts of the entire product life cycle to strategies for quality exploitation of the same and to assess the potential ways of integrating environmental aspects and quality improvements into the strategic decision making of firms.

Finally, the LCA methodology was part of different research projects in the olive oil sector, such as the ECOIL project in Greece (ECOIL 2006), the OiLCA project in SUDOE area (Spain, Portugal and France) (Busset et al. 2012), the EMAF Project in Italy (Salomone et al. 2013), and the Life + ECCELSA project in Val di Cornia, a rural area in the south of Tuscany, Italy (Iraldo et al. 2013).

2.2.2 Life Cycle Costing

Economic tools, also in the agro-food sector, can be combined with LCA in several ways (though not completely integrated) as a separate complementary analysis, within a toolbox or as a way of expanding it.

Generally speaking, these tools can play two main roles in Life Cycle Management (LCM): on the one hand, they can provide ways of accounting for costs within the same boundaries and with reference to the same functional unit (FU) as in LCA (microeconomic-oriented accounting tools); on the other hand, macroeconomic-oriented accounting tools, such as Input-Output Tables, either in monetary or in physical terms (in the latter case leading to Material Flows Analysis -MFA), aim at studying the way materials and substances flow through the economy.

As far as the accounting for costs at microeconomic level is concerned, although Life Cycle Costing (LCC) is not as standardised as LCA, there is a significant body of literature that addresses its conceptual framework and methodology. Thus, applications to food products, being just applications of more generalised concepts, might seem not to pose major methodological problems: there are, in fact, evidences that LCC is, also, being used as a decision support tool within LCA of food products. Yet, literature provides few applications of LCC to food products and, more generally, to nondurable products: in this sector, applications of traditional LCC make sense only if an investment in some brand new food production plant is being evaluated. Furthermore, the approaches adopted when LCC is used within environmental management may vary significantly: cost elements, especially subsidies and the external costs, are expected to heavily affect the ranking of alternative options, unless one specific option is found to be both environmentally sustainable and cost effective compared with the others.

On the contrary, examples of expansion of LCA by means of combined environmental-economic analyses include applications of Input-Output Analysis along with MFA and LCA. In this case, as said before, macroeconomic-oriented accounting tools, such as Input-Output Tables are used. They can be either used in hybrid LCA of food products to extend the system boundaries to include all the complex transactions that characterise the entire economic system: such an approach has been used even at the institutional level to support integrated product policies; or they can be used to reveal the importance of understanding the physical structure underlying any food production system. The combination of macroeconomic analysis and LCA may prove to be particular useful since, compared to detailed life-cycle inventories, many models of entire economics employ a much smaller number of categories for representing production and consumption activities (Settanni et al. 2010).

As regards the application of LCC, or another kind of economic analysis, among the olive oil sector, the literature review highlighted seven studies (from 2003 to 2013): in particular, five of them are about the integrated application of LCA and LCC (Notarnicola et al. 2003; Notarnicola et al. 2004; Rosselli et al. 2010; Carvalho et al. 2012; De Gennaro et al. 2012), one is about the application of a sustainable model (economic and environmental analysis) (Palese et al. 2013) and the last one is about an energy, economic and environmental analysis (Pergola et al. 2013). Of the seven papers, just four were deeply reviewed because three of them (Notarnicola et al. 2003; Rosselli et al. 2010; and Pergola et al. 2013) are parts of other papers (respectively: Notarnicola et al. 2004; De Gennaro et al. 2012; Palese at al. 2013).

As for the LCA studies (see Section 2.2.1), the most of the LCC studies are of a comparative nature (organic vs. conventional extra virgin oil; different olive-growing systems; alternative agronomical techniques vs. conventional ones). Regarding the geographical boundaries of the examined papers, four are focused on Italian case studies (Notarnicola et al. 2004; Pergola et al. 2013; De Gennaro et al. 2012; Palese et al. 2013), and one on an European case study (Carvalho et al. 2012). Furthermore, just two papers are focused on the food product 'olive oil', respectively extra-virgin olive oil (Notarnicola et al. 2004) and olive oil (Carvalho et al. 2012), while the others are about olive-growing models or agronomical techniques.

The paper of Carvalho (2012) was developed among the OiLCA international project with the aim of improving the competitiveness of olive SUDOE space (Spain, Portugal, and the South of France) reducing the environmental impact of olive oil production through the application of the principles of eco-efficiency. This paper does not develop a comparative study, aiming to identify opportunities of waste management among the olive oil production using cutting edge technology that takes into account economic aspects, encouraging the modernisation of the sector and contributing to improve the quality of the final product. The management of these residues represents a big challenge because of their predominance and unavoidable production; it is important, so, to take into account the available or emerging technologies which may results in both economic and environmental benefits. The study was conducted coupling the LCA and LCC methodologies, with 1 litre of olive oil as FU and the following phases as system boundaries: cultivation, oil production and packaging. Doing so, it was possible to identify improvement solutions with the associated investment and production costs, giving to business people useful tools for taking decisions based on economic (and environmental) criteria. These solutions have not yet been disclosed to the public.

Regarding the comparative studies, the one by Notarnicola et al. (2004) aims to compare the production systems of organic and conventional extra-virgin olive oil in order to assess their environmental and cost profiles and to verify if the two dimensions (environmental performance and costs) go along the same direction. For the cost assessment, in particular, the LCC methodology was applied with the same FU and system boundaries of the LCA study: 1 kg of extra virgin olive oil and all the direct (agriculture practices, harvesting, transport and oil extraction) and indirect (production and transport of the pesticides, fuels, etc.) activities. Transports of chemicals (from the factories to the agricultural fields), of materials and of workers involved in the harvesting and pruning operations (from town to orchard) and of olives (from the orchard to the oil mill) were, also, included in the system boundaries. All the related internal and external costs of the two systems are reported in the study (see Table 2.3), showing (for example) that the damage caused by conventional agriculture due to fertilisers and pestidicides use (in terms of reclamation and decontamination) costs more than twenty two times that of organic agriculture; or that the organic system is characterised by higher production costs due to the lower organic yields (this higher cost is, then, reflected in a higher market price).

Table 2.3 Internal and external costs of two systems (organic vs conventional) per functional unit (1 kg of extra virgin olive oil)

Agricultural phase	Organic	Conventional
Pesticides	0.171	0.117
Fertilisers	0.268	0.181
Lube oil	0.023	0.011
Electrical energy	0.143	0.085
Water	0.077	0.046
Diesel	0.084	0.048
Labour	4.344	2.864
Organic certification cost	0.064	-
Total (1)	5.174	3.352
Transports	0.0784	0.039
Industrial phase		

Electrical energy	0.014	0.024
Labour	0.089	0.045
Water	0.002	0.022
Packaging	0.298	0.298
Waste authority	0.015	0.015
Organic certification costs	0.009	-
HACCP certification costs	0.0009	0.0009
Total (2)	0.428	0.405
Total (1 + 2)	5.680	3.796
External costs of energy	0.664	0.533
External costs of fertilisers and pesticides	0.439	9.870

Source: Notarnicola et al. 2004.

Regarding the obtained outcomes, in the comparison between LCA-LCC conventional vs. organic extra virgin oil, if the external costs are not taken into account, the organic olive oil has a higher cost profile; on the contrary, if these costs are added to the conventional (internal) company costs and to the less tangible, hidden and indirect company costs, the organic olive oil has a lower total cost in comparison with the conventional one. All that considered, it is important to account for external costs as the European Commission is already doing in several projects as, for example, the ExternE project (ExternE 2013). As far as the LCA results are concerned, the study demonstrated that organic olive system is more eco-compatible that the conventional one by a factor of 5 due to the great difference in the TETP and FAETP categories.

Another comparative study is the one by De Gennaro et al. (2012), about the integrated assessment (environmental and economic) of two innovative olive-growing systems, the "High Density" (HDO, over 200 tree/ha) and the "Super High Density" (SHDO, over 1,500 trees/ha), during their life cycle. The system boundaries included the phases of: planting, cultivation, growing production, full production, and plant removal and disposal, with a FU of 1 t of tons olives. The production of fertilisers and pesticides were also included, while transformation, distribution and consumption were excluded because the same for the two systems. The economic assessment was performed as requested by the LCC methods using, as criteria, the Net Present Value (NPV) and the Internal Rate of Return (IRR). This analysis shows that the HDO could be considered more convenient than the SHDO (the most innovative system): in fact, despite the lower operating costs of the latter, due to the complete mechanisation of pruning and harvesting operations, these costs are counterbalanced by higher initial investment costs that the company has to face (which resulted three times those of the HDO system). Also, the HDO model has a better performance (in terms of NPV and IRR) than the SDHO one: this result is, mainly, driven by lower plantation costs, longer production cycle, higher productivity of olives and higher efficiency in the use of inputs which characterise the HDO model. Furthemore the full production phase represents the major impact for both systems (more than 75% of the whole impact in all the impact categories in HDO, between 50% and 75% in SHDO). Regarding the environmental assessment, also this analysis shows a better performance of the HDO system for all the impact categories (GWP, ODP, AP, POCP, HTP, FAETP, MAETP, TETP, NP, ADP) with a percentage ranging from 21% to 37%. The better performance of HDO system is mainly linked to a lower use of energy but also to lower chemical inputs and to higher olive yields. As far as the energy use is concerned, the full production phase is characterised by the highest energy consumptions with a percentage of 87.4 (HDO) and 75.1 (SHDO). Finally, the study highlights that results remain the same even if a sensitivity analysis (modifying the olive yields of the two systems) is carried out.

Finally, the paper written by Palese et al. (2013) is focused on the proposal of a Sustainable System (SS) for the management of olive orchards (156 plant ha^{-1} with a distance of about 8m x 8m) located in semi-arid marginal areas. This new model presents two key aspects: the reuse of urban wastewater distributed by drip irrigation and the use of soil management techniques based on the recycling of the polygenic carbon sources internal to the olive orchard. Economic (and also environmental) analysis was performed for evaluating the sustainability of the proposed method when compared to the conventional management system (CS). In particular, the economic results were expressed at constant values by the formula:

Gross Profit (GP)=Total Output (TO)-Production Costs (PC)

with:

TO representing the income from sales of oil and table olives

PC is the sum of fixed and variable costs, gross of taxes and overheads.

Data were evaluated for a period of 8 years, showing that the Annual TO (euro · ha^{-1} · $year^{-1}$), calculated at constant values, was strongly affected by the extent of the crop load measured in the examined period. In particular, TO of the SS resulted constantly positive and greater (about three times, mostly due to the higher quality of the olive production – table olives) when compared with the CS value. Regarding the PC, the SS showed higher values than CS. Both systems present a positive value of GP/ha but the SS was four times more profitable than CS. Finally, SS produced quite a regular income over the considered period thanks to the annual yield while CS guaranteed a GP on alternative years. The environmental assessment was focused, above all, on CO_2 stocks in plant and soil, and anthropogenic and natural CO_2 emissions. It demonstrates that also from this point of view the SS system is the most sustainable. By comparing the mean annual fluxes of CO_2 (Net Primary Productivity –NPP– vs. total emissions), the SS system shows a positive data with an important gain of CO_2 sequestered from the atmosphere (15.45 t · ha^{-1} · $year^{-1}$) while the CS has total emissions higher than NPP; the SS shows an annual gain of 3.85 · CO_2 · t · ha^{-1} in the first 0-0.6 m soil layer; on the contrary, CS shows an important mean annual loss equal to 5.10 CO_2 · t · ha^{-1}. Finally the SS is able to fix a higher amount of CO_2 than CS (more than the double).

All that considered, the SS appeared sustainable not only from the economic but also from the environmental and social point of view.

2.2.3 Simplified Life Cycle Assessment (S-LCA)

Environmental Life Cycle Assessment (LCA) methodologies are commonly used in product eco-design. However, in the early conceptual design stage, difficulties are encountered, due to the large amounts of data and time needed for a full LCA.

As demonstrated by Alting et al. (2007), the possibility of influencing the environmental performance of a product is bigger in its development stages, though in such phases the knowledge about the product is lower (quantitative information is often not available). Therefore, both analysis (LCA) and synthesis tools are needed to be applied at the early stages of product development. The combination of analytical tools, for assessing the impacts of products, and synthesis tools for eco-design, could be involved to contribute to the development of innovative products with improved environmental performance (Pigosso et al. 2010). According to Manzini and Vezzoli (2002), auxiliary tools for sustainable design are evolving and expanding their potential and their effectiveness in relation to criteria for reducing the environmental impact in the whole life cycle of products.

The practical use of environmental LCA methods and software tools in industry has revealed the need for simplifications for many applications. Hence, streamlined LCA methods have been derived from experience with the complex full methods (Hauschild et al. 2005). Simplified LCA (S-LCA), also known as Streamlined LCA, emerged as an efficient tool for evaluating the environmental attributes of a product, process, or service's life cycle (Hayashi et al. 2006).Le citazioni più vecchie andrebbero sostituite con quelle più recenti

The aim of S-LCA is to provide, essentially, the same similar results as a detailed one, i.e. covering the whole life cycle using qualitative and/or quantitative generic data, followed by a simplified assessment, thus significantly reducing the expenses and expended time. It has to include all relevant aspects, but good explanations can, to some extent, replace resource demanding data collection and treatment (Schmidt and Frydendal 2003). The assessment should focus on the most important environmental aspects and/or potential environmental impacts and/or stages of the life cycle and/or phases of the LCA and give a thorough assessment of the reliability of the results.

S-LCA studies can be conducted for a quick assessment of a product: the challenge is to adapt the LCA methodology and simplify its use, but to a more advanced LCA stage than for a screening LCA. S-LCA has to be interpreted as an ‘adapted’ LCA, depending on the effort that the LCA practitioner wants to put in for every life cycle stage. The minimum requirements can be summarised as follows:

- goal and scope;
- life cycle stages included, and a clear definition of the system boundaries;
- input materials/items included and excluded, with justification, as well as processes for energy, water, etc.;
- overview of calculation rules, and comments on the degree of approximation/uncertainties;
- impact categories considered (with justification);
- limitations;
- life cycle impact results and interpretation;
- statement regarding consistency;
- results.

Data used in a simplified study should, as far as possible, provide the existing time and budget constraints, related to the country where the products are produced or being used. However, as this is not always possible, it is also acceptable to use assumptions, for example using data that represent a country with a similar electric energy grid mix and manufacturing technology. The data should represent the technology used as closely as possible.

The first question to be asked when an LCA is to be performed is what purpose the study has. Is it eco-design, in order to improve a product's manufacturing process? Is it to provide environmental labelling? Or to carry out comparative studies? This initial consideration is crucial, because it will determine a number of assumptions and decisions to be taken throughout the study.

In the olive oil production sector, LCA studies are, generally, aimed at identifying the environmental burdens associated with the involved processes and at proposing actions for further environmental improvements. Nevertheless such goals are often complex tasks, mainly due to the lack of reliable input data related to the whole life-cycle of the assessed system, thus affecting the accuracy and the significance of the study. A S-LCA procedure can make possible studies based on information that is already available, e.g. at the early conceptual design stage or when input data does not allow to assess sources of environmental burdens.

Scientific literature of the sector includes few studies which specifically apply a simplified procedure. Among them, Abeliotis (2003) focuses on the analysis of a three-phase olive oil mill. It is not a comparative analysis but it aims at assessing the most environmental burdens of the examined production system. In each production stage, the input and output streams of mass and energy are identified (inventory phase) and the environmental impacts associated with the process are grouped together into a number of environmental impact categories (Global Warming Potential, Acidification, Eutrophication and Photo-oxidant Formation, etc.).

The boundaries of the system start from the fertilisation of the olive trees and end with the extraction of olive oil. Region-specific and agricultural phase LCI data are not available.

For some processes, such as fertiliser and pesticide application, although site-specific data were desirable, estimates of emission factors and estimation techniques from literature were used.

Data for the mass and energy balance at the extraction stage are derived from the examined production process, but no experimental data are available with regard to the organic load of the effluent olive mill wastes from the treatment step, N_2O emissions and the energy embedded in fertilisers. Thus these data were deduced from literature sources and data adapted to the analysed process.

This study shows that the most significant impact arisen from the assessed process is the GWP, attributed to the electricity required for the olive oil extraction process as well as the energy used for the fertiliser production. However, two relevant impacts are not taken into account (land use and human toxicity), due to the lack of specific data about a number of several sources of environmental burdens, such as the use of pesticides, and the presence of phenols in the effluent olive mill wastes. Furthermore, no data about the treatment of the olive mill wastes are available.

Another example of S-LCA study is presented in Raggi et al. (2000), where the production and use of olive husk bricks, as a fuel for residential heating, are screened and a preliminary comparison of such a technology with natural gas combustion is carried out. The system boundaries are defined as to cover all the steps from olive husk handling and pressing to its combustion in households, including the production of packaging and ancillary materials. Environmental burdens related to the oil extraction from olive cake are totally allocated to the extracted oil. With regard to data quality, primary data are collected on site directly from the economic actors involved in the product life-cycle, while literature and international databases are used for secondary data. The study presents a partial life cycle impact assessment, since only GWP and AP are investigated. Results highlight that the most significant contribution to GWP arises from the transport, followed by the energy requirement in the husk processing activities. No contribution of the CO_2 from the combustion of olive husk is considered, assuming it "virtually" equal to the CO_2 absorbed by the plants during their vegetative cycle. With regard to AP, the most significant contribution derives from the combustion of the biomass, due to the sulphur content in olive husks and the NO_x released from the boilers.

The olive husk as fuel in residential heating has been compared to the performances of natural gas technology, with regard to GWP and AP, in order to assess environmental benefits and drawbacks associated to the biomass use, but the related primary energy saving is not accounted for. The assessed husk-based heating system contributes much less to GWP than the use of fossil fuels, unless husk is transported over longer distances. However, the authors do not provide any specification about such distance. This study puts on evidence the need of higher quality data in order to avoid estimations, since many of them are missing and not accurate, such as the emission factors of husk combustion.

In the two above cited studies, the S-LCA procedure is applied as preliminary tool to assess different products of the olive oil chain. The former is aimed at evaluating the environmental burdens of olive oil produced in a three-phase mill, identifying and quantifying material and energy consumption and releases to the environment at the mill stage; the latter shows a preliminary LCA study of olive husk used as biomass in residential heating, comparing it with a fossil fuel, i.e. natural gas. Both the two studies highlight critical issues of the assessed production processes, such as the contribution to the GWP impact category, even though a more accurate analysis should also require the assessment of other impacts, such as the life-cycle energy requirement in terms of primary energy, which is strictly connected to GWP.

2.2.4 Footprint labels (Carbon Footprint, Water Footprint, Ecological Footprint)

The term "footprint" has become in general a popular means of indicating a quantitative measure of the appropriation of natural resources in human beings (Hoekstra 2008). All the three indicators, Carbon Footprint, Water Footprint, Ecological Footprint, are aimed at evaluating environmental impacts in terms of appropriation of natural resources needed to sustain the supply chain of a generic product. Specifically, the three indicators highlight the effect of resources consumption on different environmental compartments: air (in terms of greenhouse gas emissions), water (in terms of volume of water consumed and/or polluted) and land (in terms of land use) (Neri et al. 2010). The joint use of more than one indicator should provide a full sustainability diagnosis (Bastianoni et al. 2013), therefore it is very important to highlight outcomes obtained also through other methodologies, different from LCA.

In particular, the methodology of ***Carbon Footprint*** (CF) is, commonly, defined as the quantification of greenhouse gas emissions associated with the life cycle of a good or service. Referring to the life cycle, the Carbon Footprint derives from the LCA methodology, but focusing just exclusively on issues related to the phenomenon of global warming (Weidema et al. 2008). The PAS 2050 (BSI) was one of the first standards introduced in this context that standardizes a similar methodology while in 2013. Later on, ISO published the international standard rules related to this method in May 2013 (ISO DIS 14067). The unquestioned acceptance of the Carbon Footprint by retailers and media has been possible thanks to its ease of comprehension and immediacy (even for non-experts) and the explicit reference to the problem of global warming. Its diffusion has been achieved thanks to the interest arising from different sectors, including the agro-industrial one, which immediately saw the Carbon Footprint as a tool for product/image/marketing improvement and strategic communication when it comes to the consumer.

Within the olive oil sector, IOC (International Olive Council) is taking steps to drafting guidelines for a correct and uniform application of the current present standards rules. The Carbon Footprint-related scientific literature includes a small number of studies specifically related to it. Among them, only two (Lucchetti et al. 2012; Polo et al. 2012) focus on the analysis of the Carbon Footprint of 1 kg of olive oil (even though only for the bottling stage), Nardino et al. (2013) carry out an empirical and tool-related assessment about the ability to fix atmospheric carbon from the olive grove, while in Intini et al. (2011), a comparative evaluation between the use of de-oiled pomace, fossil fuels and wood biomass (in the operation of a power plant for production of electricity and heat) is carried out. Polo et al. (2012), apply the methodology of the Carbon Footprint to 5 agro-industrial products, including two types of olive oil (1 L glass and 5 L PET). The analysis shows that the CFP are of 1.1 and 5.5 kg of CO_2 (respectively for bottles of 1 and 5 litres). Furthermore, along with them, Özilgen and Sorgüven (2011) carry out an evaluation with three different methods (energy, exergy and carbon dioxide emissions) for three different oils (soybean, sunflower and olive) using 1,000 kg of raw material product as a functional unit (soybean, sunflower, olive). In this study, the agricultural phase is responsible for the most of carbon dioxide emissions due to the excessive use of fertilisers (Ozilgen and Sorgüven 2011). The total CO_2 emissions for producing oil from 1 ton of olives is 323.1 kg CO_2, of which 164.9 kg CO_2 is linked to the agricultural phase, 123.3 kg CO_2 to the oil production phase, 31.9 kg CO_2 to the packaging phase and 3.0 kg CO_2 to the transportation phase.

Three of the out of the five works analysed (Intini et al. 2011; Lucchetti et al. 2012; Nardino et al. 2013) are representative of the Italian scenario, demonstrating the attention given, at a scientific level, to the agro-industrial production in Italy. On the other hand, one of them (Özilgen and Sorgüven 2011) was developed in Turkey.

No article takes into account the olive oil product from cradle to grave. Specifically, Lucchetti et al (2012) during their analysis of the bottling process, does not use a calculation software but directly uses emission factors (published by government agencies and electricity producers). Furthermore, not all of the GHGs highlighted provided by the IPCC, but just only CO_2 and CH_4 are considered in the study. Intini et al. (2011) carry out an assessment of the benefits arising from the possible use of de-oiled pomace, for energy, taking into account both the current technologies already widespread and the nationwide availability of this product. The analysis shows what might be the avoided emissions of GHGs if all the de-oiled pomace was destined not to residential users (as happens today) but to electricity and heat production plants. The analysis made by Polo et al. (2012), although very interesting for the results achieved, does not show in any way how the data collection was conducted, nor even of what such software or database, the calculation of the carbon footprint.it was based on the calculation of the carbon footprint. The study of Nardino et al. (2013), while making explicit reference to the carbon budget within an olive grove, does not use the specific methodology of Carbon Footprint to assess what the total mass of CO_2 stored is. Indeed, some methods were proposed by Nardino et al. (2013) based on the study of gas exchange between the atmosphere and tree cultivation and compared (to assess their significance) with empirical methodologies. From this work, it clearly appears that olive grove are a strong tool for valorising carbon storage and for biomass production destined to energy purposes (values ranging between 10 t (C) ha^{-1} $year^{-1}$ and 15 t (C) ha^{-1} $year^{-1}$). In the study by Özilgen and Sorgüven (2011) it was not clear what the source of the emission coefficients was nor if the study included all GHGs or just carbon dioxide. In general, referring to the carbon footprint methodology, it can be said that it is not, at least in the olive oil sector, a frequently applied tool, both for the small number of papers in the literature and for the lack of comprehensive studies related to our subject of interest. The reasons for this refers to the fact that the method is a very recent one (ISO 14067 was published only in May 2013), to the scientific limitations of the tool, even though it allows a strong communication, and to the fact that it makes impossible to evaluate it which negative environmental burdens arise from the olive oil production.

Within the subgroup of "Labels or Footprints" also the ***Water Footprint*** (WF) is to be noted, being a water use indicator that considers both the direct and indirect costs related to a process or good and that is referred to as volume of fresh water used per unit of product. It is divided into three components (Hoekstra et al. 2008): blue WF (blue water, surface or underground), green WF (rainwater that is stored temporarily in the soil or vegetation), gray WF (volume of fresh water required to assimilate the load of pollutants).

For the olive oil sector, the literature review highlighted just one paper only the contribution of Salmoral et al. (2011) was assessed in analyzing the WF of olives and olive oil produced in Spain. The analysis was conducted over several years (1997-2008) and on data aggregated at a provincial and national level. It was found that the average value of WF at the national level is: 8,250-3,470 L L^{-1} for green WF (without irrigation), 2,770 to 4,640 L L^{-1} green WF (with irrigation), 1,410 to 2,760 L L^{-1} blue WF (with irrigation) and 710-1,510 L L^{-1} grey WF. Since the relevant literature on this subject was found to be limited, no comparative evaluation can be done with other producing nations (e.g., Italy).

The third indicator, belonging to the footprint family (Galli et al. 2012), is the ***Ecological Footprint*** (hereafter EF). It is evaluated by considering all the direct and indirect inputs that are associated with the analyzed system during for its entire life cycle (Bastianoni et al. 2013). Each of these inputs is converted in terms of the global hectares (*g*ha) needed to support their production. In particular, the EF of a final, or intermediate, product is defined as the total amount of resources and waste assimilation capacity required in each of the phases necessary to produce, use, and/or dispose of that product (Global Footprint Network 2009). If the EF is considered as a stand-alone indicator within LCA, it is defined as the sum of time-integrated direct land occupation and indirect land occupation, related to nuclear energy use and to CO_2 emissions from fossil energy use and cement burning (Huijbregts et al. 2008). Therefore EF provides a more differentiated and complete picture of environmental impact due to the combination of fossil CO_2 emissions, nuclear energy use and direct land occupation in one common metric ‘global hectares’ (Huijbregts et al. 2008). One important difference with the original EF approach (Wackernagel et al. 2005) is that product-specific yield figures are applied for forestry, pasture and crops to obtain the direct land occupation instead of global average yields (Ecoinvent Centre 2004).

Despite its diffusion and popularity, product EF applications are still scarce and, especially for what concerns the olive oil sector, there is not an adequate background of case studies to highlight appropriation of natural capital, efficiency of natural resource use and environmental pressure related to this sector. Indeed, up to now, studies focused on the EF of olive oil production processes and phase by phase assessments, are still not published. The olive oil product is always grouped into the category “’oils and fats’” related to per-capita consumption in Territorial Footprint assessments, without any clear reference to each component alone. The only one available data, obtained by using the original EF approach (Wackernagel et al. 2005), highlights a requirement of 905 gm^2 per capita for the annual consumption of 12 kg olive oil (75.4 gm^2 per capita for 1 kg olive oil consumed) of which 89.3% is due to the cropland area type and the remaining 10.7 % to the CO_2 area type (Scotti et al. 2009). This study refers to the municipality of a northern area in Italy, therefore it is a very specific and local outcome.

Deepening studies on EF application to the olive oil sector should be desirable to monitor the combined impact of anthropogenic pressures that are more typically evaluated independently and could thus be used to understand, from multiple perspectives, the environmental consequences of human activities. In this sense, it would be interesting to know how big the EF related to the agricultural practices, to the oil mill and waste management could be, highlighting which phase requires more biologically productive area in terms of earth’s regenerative capacity. From the comparison between EF and biocapacity (i.e. the ecological balance), related to olive oil production, it would be possible to assess how big the deficit could be the deficit. Probably the re-use of part of wastes as fertilisers may reduce the overshoot and decrease the farm dependence on additional external goods. The main strength of the EF methodology is the possibility of its ability to explaining, in simple terms, the concept of ecological limits, thus helping to safeguard the long-term capacity of the biosphere to support mankind and understand how resource issues are linked with economic and social issues (Bastianoni et al. 2013). In this sense, EF could be an effective and immediate tool to communicate how much agricultural and transformation practices in the olive oil sector go beyond ecological limits and how to manage and use available resources in a sustainable way.

The olive oil sector is also assessed using other methodologies different from footprint labels. For example, ***Emergy, Energy and Exergy evaluations*** can provide a set of information on the human processes ‘un’-sustainability from other viewpoints (e.g. eco-centric viewpoint), that LCA does not take into account (e.g. human labor). In particular, emergy (Odum 1996) provides an estimate of the environmental work required to generate goods and services from a ‘donor-perspective’ (Ridolfi and Bastianoni 2008). Applications of these three methods to the olive oil production chain are few. Recently Neri et al. (2012) compared organic and conventional productions in Italy using emergy evaluation. This study highlights that both systems present higher values related to the agricultural phase, even if the organic farm shows higher environmental performances for all phases. The conventional system uses resources that are renewable for 4%, while the organic one 12%. Human labor represents 4.33% and 25.10% of total emergy flow for conventional and organic systems, respectively. This study is the only one that shows the importance of human labour, that is a fundamental topic in the olive oil sector, along with the agricultural, transformation and packaging phases.

Agriculture is also the most energy and exergy intensive process, with diesel being is the dominant energy and exergy source (Özilgen and Sorgüven 2011). In this study, the use of waste vegetable oils converted into biofuel, as an alternative to diesel in heating oil burners, is proposed as an improvement.

A comparison between organic and conventional systems is also provided by an energy use assessment in Spain (Guzman and Alonso 2008). This case shows the lower energy efficiency of irrigated land as opposed to dryland (i.e. non-irrigated) regardless of their style of management and, on the other, the greater non-renewable energy efficiency of organic olive growing in comparison with the conventional production. The use of 'alperujo' (olive wet husk) compost and temporary plant covers and the reduction of machinery to use when it is strictly necessary are proposed as possible improvements.

These studies highlight the importance of resources valorisation and renewability of different production management.

2.2.5 Product Category Rules (PCRs) and Environmental Product Declarations (EPDs)

The Environmental Product Declaration (EPD) is a verified document containing the quantification of the environmental performances of a product or service by the appropriate categories of parameters calculated using the methodology of Life Cycle Assessment (LCA). This methodology allows the EPD to provide objective information by which all the aspects that lead to continuous improvement of environmental conditions related to the production of a product or service can be identified .The EPD communicates about the environmental performances of products and services with key characteristics and guidelines that result in a number of advantages for organisations that use the EPD and for those using EPD information (http://www.environdec.com/en/What-is-an-EPD/). Currently different EPD schemes exist: EPDs program (Canada), Jemai Type III program (Japan), Type III program NHO (Norway), EPD System (Sweden), KELA Type III program (South Korea).

The requirements for EPDs of a certain product category are defined into Product Category Rules (PCRs).

As far as the food products are concerned, numerous PCRs have been developed, including the one for the product category "virgin olive oil and its fractions"; the product category includes "virgin olive oil" made, according to the definition contained in the International Olive Council website (www.internationaloliveoil.org) and according to the Reg. EC 1019/2002, EC 796/2002 and subsequent amendments. On the contrary, 'lampante' virgin olive oil and olive-pomace olive oil are excluded.

On the basis of what is reported in the reference PCR, when developing the EPD, the functional unit of 1 litre of virgin olive oil must be declared as a unit of product including also the packaging; it is necessary to declare, in addition, information on the end of life phase of the packaging.

Data for the following materials and substances, derived from analytical determinations, must be included

- virgin olive oil and its components both beneficial and harmful to human health;
- traces of plant protection products (PPPs) as potentially harmful to human health;
- traces of phthalates as potentially harmful to human health.

The system boundaries included in the PCR provide general 'upstream', 'main', and 'downstream' processes.

In particular, the "upstream processes" must include the flow of raw materials and energy necessary for the production of virgin olive oil.

In "process" raw materials, extraction of virgin olive oil from the olive fruits, waste management, storage of olive oil, and primary packaging (including transportations) must be included in the 'main process'.

Finally, the downstream processes must include transportation from the production site/retailer to the final storage, waste management/recycling, the use of the product to the customer or consumer, recycling or waste management of packaging/materials after use.

In the EPD, the environmental performances associated with each of the three phases of the life cycle are reported separately. Also, all the data reported in the EPD are subjected to an independent verification of the declaration and data, according to the ISO standard 14025:2006. Furthermore, every year, the declaration has to be updated and reviewed every three years.

After the issuing of the PCR for olive oil by the International EDP® System, the interest among olive oil industries towards the EPD increased (International EDP® System 2010). Nowadays, eight EPDs are registered with 7 of them referring to Italian olive oil industries or associations. In particular, the first experience involved 68 Greek olive growers from Peloponnese and Crete, organised by 3 farmers' organizations: Nileas, Pezea Union and Mirabello Union. This experience was soon followed, among the Italian context, by the EPDs achieved by, the firm APOLIO (Cappelletti et al. 2012), by the association ASSOPROLI Bari and by the firms De Cecco and Monini; this latter certified 4 different types of extra-virgin olive oil: “Granfruttato”, “Classico”, “Poggiolo”, and “Delicato”.

Through a deep analysis of the data referred to the environmental performances reported into the eight EPDs, some differences can be highlighted. This is not only due to the variety of the analysed systems (olive groove management, olive oil extraction system, packaging and transportation), but also due to the different assumptions made when system boundaries were defined. As for this issue, indeed, even though with some differences for the data inventory, all the EPDs include the agricultural phase (upstream phases), while this is not the same as far as the downstream phases are concerned..

Since the PCRs are lacking in terms of reference specific indications, in some cases only the transportation from the olive oil mill to the retailing were included. In other cases also the use phase and end of life of the packaging material were also included.

These different assumptions, understandably, contribute to increase the variability of the total results. Starting from the upstream phase, it pointshould be edpoint out that the comparison among the different types of olives cultivation cannot be done due to the lack of detailed information. Sure enough, the EPDs give information about olive groove managing system, but there are no quantitative and qualitative data as far as agricultural practices are concerned: these details could be very useful, especially regarding the business relations with the large-scale retailer.

As regards to the analysis of the core phase, the information about the olive oil extraction processes are not always complete. The processes were often, described in a generic way and unclear aspects were presented in the related environmental performance. As for the EPD registered by the firm De Cecco, an olive oil extraction technology, which produces very polluting wastewater, especially as for the eutrophication (Cappelletti et al. 2009), was described. Nevertheless, the value of the eutrophication potential declared is zero and no details are given in order to explain this result.

By analysing the packaging phase, the choice of the container is a further aspect which influences the variability of the results. Indeed, although the functional unit is always one litre of extra-virgin olive oil, the glass container used, is sized in some cases 0.5 litre (ASSOPROLI Bari), in other cases 0.75 litre (group Nileas, Pezea Union e Mirabello Union) and in others again 1 litre (APOLIO, De Cecco, Monini). In all the EPDs the high environmental impact related to the production of the glass container (bottle) is highlighted. This entails that, by considering the same functional unit, the biggest container is advantaged (less kilograms of glass per litre of extra-virgin olive oil (Cappelletti et al. 2007).

In the downstream phases, the environmental performances, in some cases, were exclusively related to the transportation from the olive oil mill to the retailers (group Nileas, Pezea Union e Mirabello Union), while, in others, also the transportation to the consumer and the packaging disposal were considered (ASSOPROLI Bari, APOLIO, De Cecco, Monini). However, the environmental impacts related to the phases mentioned above influence very little the total of the impacts declared. As far as the disposal of packaging is concerned, it must be considered, furthermore, that the environmental performances are influenced by the assumptions made for the packaging phase (type of container) and by the behaviour of the consumers. So, for the calculation of the environmental impacts estimates, data deriving from literature were, principally, used.

Definitively, the comparison of the eight EPDs shows that the environmental performances are declared by following the scheme defined by the PCR and the GPI (General Programme Instructions). In most of the cases, the evaluation methods are clearly described as well as the impact categories (as defined by PCR).

By comparing the aggregated data referred to the environmental performance, among the EPDs registered for the olive oil, a significant variability of the results is highlighted. In all cases the results underline the high environmental impact of agricultural phases: for almost all the impact categories analysed, over the 50% of the total impact derives from the olives cultivation phase. This is an aspect frequently observed when a LCA study is carried out among the olive oil sector (Salomone et. al. 2010); this also represents a typical hot spot of the agro-food sector, towards which further efforts should be oriented in order to reduce the environmental impact (Salomone et al. 2013) and decide on the best practices to be applied to the whole sector (Regione Puglia 2013).

Table 2.4 Environmental Performance referred to the olive oil EPDs

	Unit	F.G.N. P.U. and M.U.	Apolio	Assoproli	De Cecco	Monini Granfruttato	Monini Classico	Monini Poggiolo	Monini Delicato	Min	Max	Average	St. Dev.
Non Renewable Material	Kg	0.4	0.2	0.3	1	0.6	0.7	0.7	0.7	0.2	1	0.6	0.3
Non Renewable Energy	MJ	18.6	8.1	40.6	17.3	59	47.5	45.7	53.3	8.1	59	36.3	18.9
Renewable Material	Kg	0.1	9.8	0.1	0.0	3,789.3	11,953.1	12,525.8	10,106	0.0	12,525.8	4,798	5,758.2
Renewable Energy	MJ	1.5	0.3	3.1	2.3	1	1.3	1.3	1.2	0.3	3.1	1.5	0.8
Use of Water	m^3	0.3	0	0.5	0.5	3.8	12	12.5	10.1	0	12.5	5	5.6
Use of Electricity	MJ	8.3	0.1	4.3	3.1	1.3	1.9	1.9	1.8	0.1	8.3	2.8	2.5
ADP	kg Sbeq.	0	0	0	0	26.2	15.4	19.8	23.4	0	26.2	10.6	11.7
GWP	kg CO_2eq.	2.5	1.3	2.8	2.5	4	3.2	3	3.6	1.3	4	2.9	0.8
ODP	kg CFC-11eq.	0	0	0	0	0.4	0.8	0.8	0.7	0	0.8	0.4	0.4
AP	kg SO_2eq.	0	0	0	0	28.3	17	15.8	20.6	0	28.3	10.2	11.5
POCP	kg C_2H_4eq.	0	0	0	0	6.7	2.9	2.5	4	0	6.7	2	2. 5
EP	kg PO_4eq.	0	0	0	0	6.6	15.6	16.5	13.7	0	16.4	6.5	7.6
FAETP	kg 1,4-DBeq.	0.8	0	0.7	0.1	106	397.9	421.54	334.3	0	421.5	157.7	192.8
MAETP	kg 1,4-DBeq.	1,692	563.6	1,129.6	221.4	2554,953	888,356.9	938,502.6	751,467.7	221.4	938,502.6	354,610.9	429,897.6
TETP	kg 1,4-DBeq.	0	0	0	0	2.5	7.2	7.5	6.2	0	7.5	2.9	3.5
HTP	kg 1,4-DBeq.	5.402	0.175	2.733	0.339	2,156.038	1,489.442	1,417.620	1,683.583	0.175	2,156.038	844.417	926.341
Land Use	m^2x yr	9.723	23.064	23.391	2.055	0.058	0.060	0.061	0.060	0.058	23.391	7.309	10.354

Source: www.environdec.com

2.2.6 Other tools

The assessment of the eco-profile of a food product system is a complex task due to its huge overlap with other product systems and to uncertainty, which often affects the results of the analysis (Avramides et al. 2008).

Olive oil is one of the most representative product of the food sector in the Mediterranean area and, related environmental LCA studies show significant environmental impacts associated to the resources consumption and waste releases from the relative agricultural stage and production processes (Ardente et al. 2010; Cellura et al. 2012). Due to the complexity and heterogeneity of agricultural processes, such as the crop variety, and the different levels of mechanisation in field, suitable methodologies to quantify the environmental sustainability of the olive oil chain are needed. In such a context, decision-making support tools, in particular Multi-Criteria Analysis (MCA), could aid LCA experts to select, among different options, the one which reaches the best environmental performance, according to a set of criteria defined by the decision-maker (Beccali et al. 2002a; Beccali et al. 2002b).

Within the specific literature there are some studies on the integration of LCA and Multi-criteria Analysis (MCA) methods, as effective tools to analyse the olive oil production chain (Beccali et al. 2003). Among these, Recchia et al. (2011) assess different scenarios concerning the agricultural phase, the olive transport from the grove to the mill, and the extraction phase. The application of MCA analysis identifies five optimal scenarios, according to the evaluation criteria defined by the following rules: 1) five environmental criteria, preferring scenarios characterised by low level of field mechanisation, short transport distance and high efficient extraction plants exploiting reused energy from field and plant wastes (pruning and pomace stone); 2) three economic criteria, taking into account harvesting and pruning costs and olive productivity. The weighed ranking derived by the MCA shows that the highest score is assigned to the high-intensity scenario characterised by a high score in the economic criteria, due to the mechanised field management and a significant olive yield, and a medium score in the environmental criteria, due to the reuse of pomace and pruning residues. Within the ranked scenarios, the one characterised by economic drawbacks, due to a low level of mechanisation and low olive productivity, shows the lowest environmental impact, due to the presence of traditional grove with olive mill inside. Then, LCA is applied to the above five scenarios in order to identify the one with the lowest environmental impacts, in terms of Global Warming Potential (GWP) and Global Energy Requirement (GER). The results of the LCA endorse the ones results of the MCA: the traditional grove scenario involving the lowest GWP and GER. This outcome is essentially due to the absence of organic fertilisation and irrigation plants and to the reuse of prunings as biofuel for the mill energy requirement. On the opposite, the worst eco-profile is involved by the high-intensity scenario, where by-products (pomace and vegetation water) are treated as waste.

In other studies, multi-criteria analyses are used for the interpretation of LCA results. Among these, in Cavallaro et al. (2010) the joint-use of LCA and a multi-criteria algorithm is developed, applying it to the olive oil chain. The tool derives from PROMETHEE (Preference Ranking Organization Method on Enrichment Evaluation) (Brans et al. 1985), using the outranking approach based on a pair-wise comparison of alternatives for each criterion. Such a tool is applied to eight scenarios of conventional and organic olive oil production, assessed with a life-cycle approach. The results show that the preferable scenario is the conventional tree cultivation, oil extraction with a three-phase system, and co-composting of olive husk and olive mill wastewater (the obtained compost is considered as an avoided production of fertilizer and stones as avoided production of fuel). On the contrary the worst environmental performances are related to two scenarios: one with organic olive tree cultivation and other one with a large use of pesticides and chemical fertilizers.

In conclusion, although there are few studies in literature, the integration between LCA and MCA has proven to be particularly useful to better understand complex comparisons among different scenarios of olive oil production, which are generally characterized by many differences in single processes (e.g. pest treatments, cultivation management, olive oil extraction technologies, etc.).

2.3 Methodological problems connected with the application of Life Cycle Assessment in the olive oil production sector: critical analysis of the international experiences

In order to highlight the main methodological problems that emerge when LCA is applied to the production of olive oil, a previous analysis conducted only on Italian case studies (Salomone et al. 2010b) was widened and deepened, performing a critical analysis of the international experiences of LCA in this specific sector. The critical analysis followed three basic steps of investigation:

1. mapping of the international LCA studies on olive oil - on the base of the state-of-the-art analysis presented in Section 2.2 it emerged that, at the 30th September 2013, 72 studies have been published on olive oil, olives in general (for oil or table use), olive oil mill waste treatment and valorisation, and table olive and olive oil packaging (see Table 2.1). With the aim of clearly identifying the specific applicative and methodological problems encountered when LCA is applied in the olive oil sector, the critical analysis hereafter presented was focused only on the applicative case studies that used the LCA methodology directly or indirectly connected with the olive oil production supply-chain, so that papers reporting literature reviews, methodological discussions, application in the ta-

ble olives sector, and applications of other LCT tools different from LCA were excluded (thus 50 scientific articles were included in the following analysis);

2. data collection concerning the applicative and methodological aspects related to the identified case studies - after the mapping, all data relevant for the comparative analysis were collected for each study by using a dual input channel information flow:
   - a checklist, following the ISO 14044:2006 requirements structure (ISO 2006), for the collection of the most important information contained in the published study;
   - a questionnaire, aimed to highlight the main issues not directly deductible from the paper; pursuing this goal, the questionnaire was directly completed by the authors of each study and it was been, therefore, used to gather the information not contained in the published work, but essential for the correct understanding of the most important issues concerning the applicative and methodological aspects encountered by applying LCA in this specific sector of analysis (it is necessary to clarify, however, that 24% of the questionnaires were not compiled because the authors did not reply to the request for collaboration with this research);
3. implementation of the comparative critical analysis - the collected data were then organised into a database in order to simplify the comparative and critical analysis of the international experiences gathered and to highlight common features and/or differences connected to the investigation of the fundamental aspects of LCA studies.

The 50 analysed case studies show very heterogeneous characteristics in size, content and deepness of analysis; they report results, more or less exhaustive, about applicative case studies carried on cultivation of olives, olive oil extraction, olive oil packaging and/or treatment of waste of the olive oil industry. As far as the form of publication and the methodology used, these studies show, however, more homogeneous features. In fact, the papers were mostly published in conference proceedings (42%) and in scientific journals (30%), while 12% are Environmental Product Declarations (EPDs), and the remainder (about 16%) consists of other types of documentation, such as book chapters or reports. As explained in Section 2.2, grey literature could be missing.

The LCA methodology was used as a single tool in 66% of the papers (including two cases of Simplified-LCA) or together with other assessment methods (such as Life Cycle Costing or other kind of economic analysis - 10% -, and Carbon Footprint and Emergy analysis - 4% -), or communication tools (indeed papers containing EPD descriptions or EPDs represent 20% of the gathered documents).

Focusing on the ISO 14044 specific requirements, LCA case studies present various characteristics that are briefly described in the following sub-paragraphs with the aim of highlighting how the main applicative and methodological aspects were dealt with in the international case studies.

2.3.1 Goal and scope

The goal and scope of an LCA shall be clearly defined and consistent with the intended application (ISO 14044:2006, 4.2.1), because from its delineation will depend the choice of the functional unit, the identification of system boundaries, the time horizon of the study, and, in more general terms, the deepness and direction of the whole study. As shown in Figure 2.1, most of the papers surveyed have mainly as scope the evaluation of the potential environmental impacts (60%), the identification of environmental burdens (58%), the identification of hot spots (35%), and the evaluation of improvement opportunities (32%) (each study may have more than one goal). Also the various kinds of comparative evaluations (totalling about 39%) and the company sensitisation (18%) are among the main goal and scope of the surveyed case studies. While all the studies unambiguously state the reason for carrying out the study, no one clearly define the intended audience, except EPDs that obviously are disclosed to public.

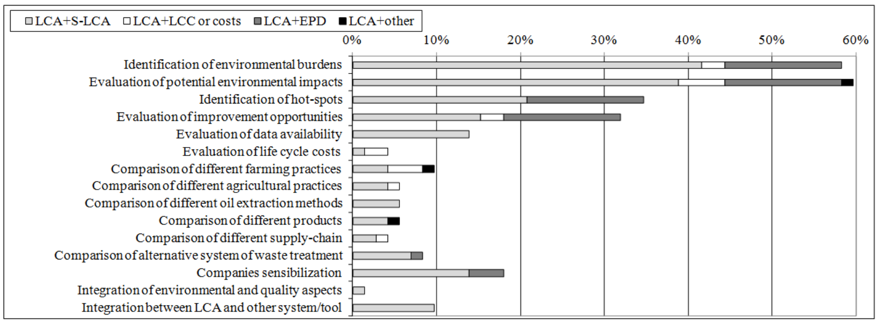

Fig. 0.1 Goal and scope in the surveyed case studies

2.3.2 Functional Unit

Figure 2.2 shows the functional unit (FU) adopted in the case studies surveyed. The FU shall be consistent with the goal and scope of the study (ISO 14044:2006, 4.2.3.2). In most of the papers the FU is a certain amount of olive oil (1 kg, 1 L or 0.75 L) with different dictions (olive oil, virgin olive oil, extra-virgin olive oil or simply oil), but it does not seem that the diction has a specific load in the goal and scope of the analysis, except few cases, as for example the one in which a specific reference to the quality characteristic of the product was inserted (Salomone et al. 2009). However, when selecting the functional unit for the olive oil chain, it should be noted 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) (see Section 2.1.1).

Therefore, choosing 1 L of virgin olive oil as the FU is not equivalent to choosing 1 L of olive oil, because they are two very different products in qualitative terms. But, the 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). The investigation performed involving the authors of the case studies allowed to highlight that 24% of the responding authors declared to have met difficulties in choosing the FU, mainly linked to the comparison of completely different olive oils. Indeed, the 50% of the analysed papers report on comparative studies mainly focused on the comparison of cultivation practices and of the different olive oil extraction methods (see Fig. 2.3). Exploring the answers of authors participating to the investigation further information can be outlined; for example, it can be observed that 36% of authors of comparative studies declared to have problems in the definition of goal and scope requirement, while only 16% of authors of non comparative studies had problems in this phase of the LCA study. Going into more details of comparative studies, the main problems in goal and scope definition were mainly linked to the

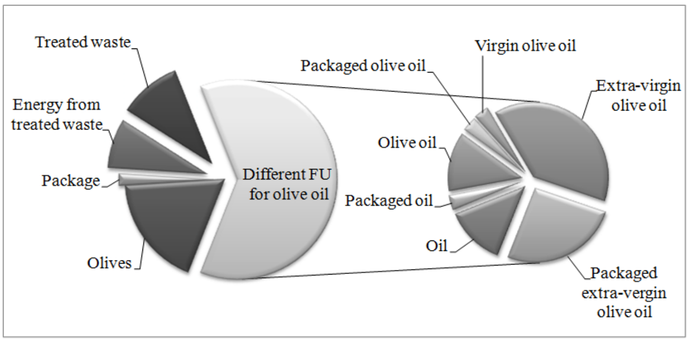

Fig. 0.2 Functional unit (FU) in the surveyed case studies

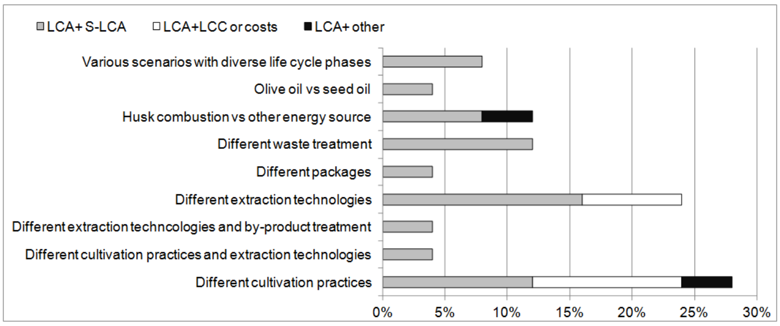

Fig. 0.3 Object of investigation in comparative case studies

choice of a proper FU (78%): the chosen solution was often the simplification and 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 olive oil or of olives was chosen as a functional unit. Olives as FU are generally chosen when the analysis is limited to the cultivation phase or when the whole production chain, including olive oil waste treatment, is included. The choice of the functional unit, however, was strongly related to the purpose of the study and to the system boundaries.

2.3.3 System boundaries

When choosing the system boundaries, the surveyed studies adopted different methods; thus, general conclusions cannot be drawn from the results reported in the various scientific articles, 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 husk compost and different types of husk, waste/by-product 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).

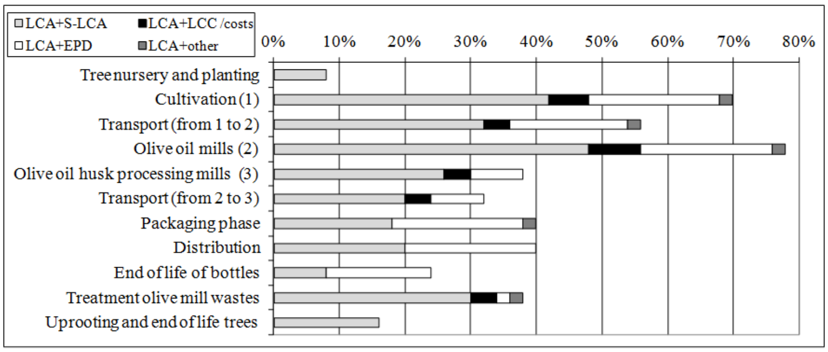

Fig. 0.4 System boundaries in the surveyed case studies

Despite these differences, however, it was possible to verify, as shown in Fig. 2.4, the chain phases that have received the most attention: cultivation, olive oil production, transport linked to these processes and olive oil mill by-product/waste treatment (including both the treatment in the olive oil husk mill and other types of treatment of olive oil mill by-product/waste).

The deletion of life cycle stages, processes, inputs or outputs is only permitted if it does not significantly change the overall conclusion of the study; any related decision shall be clearly stated and the reasons and implications for their omission shall be explained (ISO 14044:2006, 4.2.3.3). Of the analyzed studies, 74% specified exclusion of some processes from the system boundaries mainly because, being a comparative study, the processes were common to the systems analysed (24%), while in the other cases the reasons are mainly linked to missing data and/or incomplete information (24%), but rarely implications are clearly stated.

Even if system boundaries and exclusions were not clearly detailed in all studies, the analysis revealed that: 70% of the studies included in the analysis the cultivation phase that was organic cultivation in only one case, in 11% of the cases integrated cultivation, in 31% conventional cultivation, while 29% studies included a comparison of two or three farming systems (conventional, integrated, organic); on the contrary, in the other studies including the cultivation phase, the farming practice typology was not specified. In 54% of the case studies, the cultivation systems were also differentiated according to the agronomic technique (dry 37%, irrigated 37% or both 15%). Furthermore, only 11% of the studies that included the agricultural phase in the system boundaries also accounted for olive grove planting, while 40% explicitly state that excluded this phase was excluded mainly due to missing data (43%), to the consideration of the cultivation of more than 25 year-old olive trees (36%), or because of the comparative nature of the studies (14%).

Concerning the olive oil extraction phase, the analysis revealed that: 46% of studies that included this phase analysed the three-phase continuous system (including three cases of de-stoning process), 8% the two-phase continuous system, 8% the discontinuous system, 5% the continuous centrifugation with a two and a half-phase system (also called modified system or water saving system), 23% investigated a comparison of different olive oil extraction methods, while the remainder not specified the used technology (therefore not in compliance with data quality requirements – see Section 2.3.4).

Focusing on the 76% of case studies including olive oil mill by-product/waste treatments, 50% include the treatments of olive oil husk in olive oil husk mills, while the remaining refers to other treatments of olive oil wet husk and olive oil wastewater. In particular, only 8% of studies only focused on this phase of the life cycle, while in the other cases two or more life cycle phases were considered together with the waste/by-product treatment.

2.3.4 Availability and quality of data

Data quality requirements should address time-related, geographical and technology coverage; data should be precise, complete, representative, consistent and reproducible; sources of data and uncertainty of the information should be clearly stated (ISO 14044:2006, 4.2.3.6.2).

In the analysed case studies 76% of the studies specified geographical boundaries, whereas 54% specified the temporal ones (all the studies that specified temporal boundaries also specified geographical ones). Technological coverage is almost always specifically stated when different olive oil extraction methods are considered (as previous observed, only 10% of case studies including the olive oil extraction phase do not specify the method).

Ninety-four percent of the analysed papers used primary data collected from various companies of the olive oil sector, 86% used LCA database and 21% used data available in literature. The most used databases were Ecoinvent (54%), SimaPro Database (30%), Buwal 250 (21%), ETH-ESU 96 and IVAM LCA 3 (both cited in 16% of studies), PE International Database (9%). In 40% of the studies data quality was verified with various methods of analysis, of which 80% was sensitivity analysis.

Concerning data availability, 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 CO_2 emission balance.

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

- 53% of the authors who responded to the investigation, lamented the lack of data about the production of pesticides in databases; 13% of these excluded the

process from the system boundaries and 75% of the studies used data in the database for similar compounds and weighted the results based on the active ingredient;
- 40% of the authors lamented the lack of data on fertilizers production in the databases and their solution was always to use data in databases modified according to the content of N, P and K;
- 7% 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;
- 53% 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 25% of the studies (such as the successive enhancement of the model Hauschild 2000; Birkved and Hauschild 2006; Dijkman et al. 2012); in 50% of the cases the emissions were estimated using data in the literature or were considered to be similar to other compounds and in 13% of the cases they were excluded;
- 43% of the authors lamented the lack of data regarding emissions from fertilizer use and the difficulty to calculate the dispersion in soil, air and water; the solution in 31% of the cases was to use estimation models, such as Brentrup model (Brentrup et al. 2000) for nitrogen compounds, and data from literature for the behaviour of phosphorus and potassium fertilisers; in 62% of the cases the substances contained in the fertiliser were calculated with estimation from literature (e.g. using the ratio between real weight and molecular weight and then estimating emissions to the air, water and soil);
- 37% of the authors had problems in 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 mainly (82%) to consider the emissions to be derived from fuel consumption.

Other issues encountered in these studies are connected to balance of CO_2 emissions and lack of some characterisation methods. The balance of CO_2 emissions was difficult to determine for the 33% of the responding authors due to a lack of specific data, and the solution was to use generic data collected from the database, if available, estimation from literature or the exclusion.

2.3.5 Allocation methods

Whenever possible, allocation should be avoided by dividing the unit process to be allocated into two or more sub-processes or expanding the product system. When allocation cannot be avoided, the allocation procedures should be clearly stated and explained and, whenever several alternative seem applicable, a sensitive analysis shall be conducted (ISO 14044:2006, 4.3.4).

Thirty-six percent of the applied studies used some form of allocation: of these analyses, 56% used allocation methods for olive oil and for olive oil husk; 17% used allocation among olive oil, husk and olive stones; 11% for the various products of the oil-husk industry; and 6% for sunflower oil and meal; some (11%) studies applied allocation also for husk and wastewater or for different products resulting from wastewater treatment.

In the studies including allocation, this was calculated in 33% of the cases based on the price, in 11% of cases by mass, in 28% of cases by price and mass and the remainder did not mention the allocation method.

Allocation, especially in systems where the various waste treatment technologies are included, was considered a problem by 37% of the authors who responded to the investigation. These authors cited different motivations mainly connected on how to allocate the environmental load of the olive oil extraction process (among olive oil and the other by-products), but also difficulties on the representation of the reuse of pruning residues as natural fertilizers. The most common solutions cited by authors were the expansion of system boundaries in order to include the process and calculate the advantage obtained from the avoided product or the application of allocation using different methods coherently with the scope of the analysis.

2.3.6 Life Cycle Impact Assessment (LCIA)

The LCIA shall be carefully planned to achieve the goal and scope of the study. The mandatory elements of LCIA shall include the selection of impact categories, the classification and characterisation, while optional elements are normalisation, grouping, weighting and data quality analysis (ISO 14044:2006, 4.4).

Regarding the impact assessment, only 12% of the studies reported all phases of LCIA. Classification and characterisation results were described in 90% of the cases, normalisation in 36% of the cases, grouping-evaluation in 16% of the cases and weighting-evaluation in 20% of the cases.

The identification of the selected impact categories and related assessment methods was particularly complex because 14% of papers lacked sufficient elements to be able to detect the full data. Focusing only on papers in which the information was specified, the most used evaluation method was the CML in its various versions (28%), followed by Eco-Indicator 99 (26%), EPS 2000 (16%), ReCiPe in its various versions (14%), IPPC 2007 (12%), Impact 2002 (9%), and EDIP 96 (7%). Sometimes, 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 (92%), Acidification (82%), Ozone layer depletion (78%), Photochemical oxidation (74%), and Human Toxicity (60%).

2.3.7 Interpretation and tools supporting the interpretation analysis

Life Cycle Interpretation phase comprises several elements such as: identification of the significant issues, an evaluation that considers completeness, sensitivity and consistency checks, and conclusions, limitations and recommendations (ISO 14044:2006, 4.5).

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 consent to reach unequivocal conclusions. However, it can be certainly outlined that the 51% of studies that accounted for both the agricultural and other stages of the life cycle (with or without the intermediate stage of transport), identified the agricultural phase as the most pollutant. For the agricultural phase, the agronomic practices with the greatest environmental impact were the spreading and use of fertilisers and the spraying and use of pesticides. The most important impact categories were eutrophication, acidification and ecotoxicity (in its various forms) and the most pollutant substances were fertilisers, pesticides, and energy consumption.

Only 16% of the analyses used sensitivity analysis for the evaluation of interpretation results.

2.3.8 Critical review

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. Except for EPDs, none of the other examined studies presents elements suggesting that a critical review was carried out by external independent experts. Even if undoubtedly a CR improves the credibility of a study, it is still rarely practiced, maybe for the required additional costs, and only organisations working with environmental labeling or product declarations push themselves to demonstrate the quality of their LCA results with a CR. The International Organisation for Standardisation is actually working on a technical specification based on the critical review process in order to better specify the requirements contained in the ISO 14044; this technical specification (ISO 2013b) is still a working draft, but maybe further recommendations balancing quality and costs of LCA studies will be presented.

2.4 The implementation of the Life Cycle Assessment methodology in the olive oil production sector: lessons learned

The state-of-the-art and literature review of the international experiences of LCT approaches applied in the olive industry (presented in Section 2.2) and the critical comparative analysis of the applicative LCA case studies in the olive oil production supply-chain (presented in Section 2.3), allowed a better understanding of the specific methodological and applicative issues that a practitioner might come across when the LCA methodology is applied in the sector of olive oil production, and many points for reflection and improvement emerged.

When performing a LCA study, the first preliminary suggestion is to have a clear and deep knowledge both of the supply chain to be studied and of the full LCT methodological panorama currently available.

General methodological guidelines already exist, such as:

- the ISO standards on the LCA methodology, in particular ISO 14040 (ISO 2006b), ISO 14044 (ISO 2006c), and ISO/DTS 14071 (ISO 2013b);
- the ISO standards on environmental labels and declarations, in particular ISO 14020 (ISO 2000), ISO 14021 (ISO 1999), ISO 14024 (ISO 1999), and ISO 14025 (ISO 2006a);
- the ILCD (International Reference Life Cycle Data System) Handbook (EC, 2012);
- the ISO technical specification on carbon footprint of products (ISO/TS 14067 2013);
- the Ecological Footprint standard (Ecological Footprint Standard, 2009).

Furthermore, some guidelines are also specifically focused on food products, such as:

- Envifood Protocol - Food and Drink Environmental Assessment Protocol (European Food Sustainable Consumption & Production Round Table, 2013);
- Product Category Rules (PCR) and Product Environmental Footprint Category Rules for food and drink products (PEFCRs).

All the above guidelines highlight the importance of taking into account the life-cycle approach, including all stages from raw material acquisition through processing, distribution, use, end-of-life processes, and all the relevant related environmental impacts.

This chapter aims at deepening and addressing to further suggest best practices as suggestions that could be easily implemented by stakeholders, when LCAs of the olive oil production sector are developed. In the following, the lessons learned by the literature review and the critical comparative analysis are briefly presented in order to summarise not only what emerge from the current practice, but also which are the needs for further research work aimed at improving the LCA implementation in this specific agri-food sector; we suggest that practitioners carrying out LCA studies on olive oil should follow the following suggestions both at the level of methodological issues and of hot spots.

2.4.1 Goal and scope

Goal and scope definition is the first step of an LCA analysis and should set the overall context of the study, defining aims, methods of impact assessment and intended application. Furthermore, the scope should include the definition of the functional unit and of the system boundaries, referring them to the aim of the study. The goal and scope of an LCA implemented in the olive oil sector (as in any other sector) should be clearly defined and unambiguously state the reason for carrying out the study. This task seems particularly simple but, considering that from the goal and scope delineation will affect the choice of the functional unit, the identification of system boundaries, the time horizon of the study, and, in more general terms, the depth and direction of the whole study, caution should be putted when defining it; in particular, some element that deserve to be highlighted are:

- when presenting the scope, also the reasons for such choice should be explained (e.g if the scope is the identification of hot spots, which is the purpose of their identification and their use should also be clarified);
- the intended audience should be defined, in order to clearly understand whom the results are targeted to and which kind of use may be made of these results the audience may do.

However, in general, even of goal and scope definition requires special attention, it do not present particular applicative problems and no relevant methodological improvements are needed for the application in this specific sector.

2.4.2 Functional Unit

Choosing the Functional Unit (FU) is one of the very first critical tasks encountered carrying out an LCA study and the keystone of the whole project. The choice of the FU may vary according to the aim of the LCA study and may be determined in different terms such us functionality, nutritional value, portion size or other criteria. A functional unit is defined by the ISO 14044 norm as the "quantified performance of a product system for use as a reference unit". In addition, the ISO 14040 norm indicates that: "The functional unit defines the quantification of the identified functions (performance characteristics) of the product. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results. Comparability of LCA results is particularly critical when different systems are being assessed, to ensure that such comparisons are made on a common basis."

As highlighted in Section 2.3.2, when selecting the FU for the olive oil chain, particular attention should be paid to the diction of olive oil which may indicate very different products in qualitative terms. In this sector, although general LCA guides allow a certain amount of flexibility, with regard to the olive oil production processes the European Food Sustainable Consumption & Production Round Table (European Food Sustainable Consumption & Production Round Table, 2013) suggests that weight or volume are the most suitable; but due to the extremely wide variability of the quality of the oils (the price of an extra virgin olive oil rises from few euro per litre to few tens of euro per litre) it is very important to include also the product quality in the functional unit. But, how can the quality of a olive oil be defined? What defines the quality of olive oil? Certainly the quality of an olive oil depends on characteristics such as acidity, flavour, contents of E vitamin and tocopherols. Hence, how can the most correct FU be identified? Indeed, different authors of LCAs in this specific productive sector, encountered difficulties in choosing a proper FU, mainly when performing comparisons of completely different olive oils or when considering the whole production chain, including olive oil waste treatment.

Keeping in mind that the choice of the FU is strongly related to the purpose of the study and to the system boundaries, some guidelines could be, however, suggested as summarised in the following sub-paragraphs and in Table 2.1.

When the LCA aims at analysing the whole olive oil chain a certain amount of olive oil can be used (e.g. 1 L or 1 kg), paying particular attention to the diction of the different type of olive oil (extra-virgin, virgin, etc.), and packaging should be included specially if the LCA results should be declared in a EPD (as indicated into the PCR "virgin olive oil and its fractions" of the International EPD System®).

When the LCA focuses on one o two specific phases of the life cycle of the olive oil production, the FU should be chosen in order to better provide the reference to which the input and output data of these phases will be normalised (e.g. a certain surface of the olive grove - 1 hectare - for the cultivation phase or a certain amount of waste - 1 kg of wastewater - for waste treatment processes).

When considering the whole production chain, including olive oil waste treatment, the difficulty is choosing a FU which represents a common element; in this case a certain amount of olives might be the most suitable choice.

In comparative analysis between different oils (e.g. olive oil and seed oil), quality indicators could be used in a quantitative ways: for instance, due to the much stronger taste of the extra virgin olive oil than the seeds oil one (e.g. sunflower), one can state that the FU could be the quantity of oil needed to mix a portion of salad: in this case experimentally one can identify the two quantities which carry out the same function which will be, for example, one unit of extra virgin olive oil versus 4 units of sunflower oil.

In comparative analysis among extra virgin olive oils (the best quality of olive oils), indicators of the olive oil quality should be taken into considerations, as prices or, if available, the score which the olive oil has received at the panel test (Regolamento 3568/91).

When the nutritional characteristics of the product are in the core of the goal and scope of the study, the quantity of antioxidants (polyphenols and tocopherols) present per litre/kg of extra virgin oil could be considered. A functional unit of this kind allows to consider not only the yields per hectare (that greatly affect the environmental impact attributable to FU as oil, olive oil and extra virgin olive oil), but also the quality of the product that sometimes is overlooked in industrial production.

In addition, another suggestion to follow is to use a set of different functional units (quantity or volume, price, or panel test score, etc.) and to assess the variability of the results on the basis of the use of the different FUs in the sensitivity analysis.

Table 2.5 How to choose the functional unit when conducting a LCA of olive oil

Requirement	*Possible choices*	*Recommended when*
Functional unit	Hectare	system boundaries include only the cultivation process
	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
	Antioxidants (polyphenols and tocopherols)	if the nutritional characteristics of the product are of primary importance for the description of the system
	Olive mill waste	system boundaries include only waste treatment processes

Therefore, the choice of a proper FU of an LCA study in the olive oil sector seems to be an issue to which to pay particular attention, but, in the opinion of the authors of this chapter, no further methodological advances are needed except the advise given in this Section and in Table 2.5.

2.4.3 System boundaries

The choice of which processes should be included or excluded from the study depends on the defined goal and scope, and according to the availability and quality of data related to the analysed processes. As a consequence no specific guidelines can be drawn for this topic. In any case, it should be noted that, for EPD communication purposes, system boundaries are clearly indicated into the PCR “virgin olive oil and its fractions” of the International EPD System® which specify requirements for the definition of system boundaries (divided in upstream, core and downstream processes), geographical and time boundaries, boundaries to nature and boundaries to other product life cycles. In general, the system boundaries should, as far as possible, include all relevant life cycle stages and processes; they should be defined following general supply-chain logic, including all stages: agricultural, industrial, by-products management, transportation/distribution and consumer shopping, food preparation and cooking, consumption, and waste management. Human digestion and excretion should be included in the system boundaries, even if they remain the least studied life cycle stages of all food products. For what concerns the carbon balance, one should try to avoid to have it equal to zero, but to focus on the real verification of the carbon balance, which can be modified depending on which effect overrides the other (sequestration or emission). Of course the effect of sequestration prevails in the majority of studies that follow this approach and therefore total carbon balance is negative (thus, good for the environment).

The literature review and the critical comparative analysis presented in the previous paragraphs highlighted that, concerning the definition of system boundaries, the main problems encountered by authors of the surveyed studies were determined by the lack of significant data on some specific processes of the chain, which causes these processes to be excluded from the system boundaries, and which in turn causes the need to redefine and re-calibrate the goal and scope of the study (according to the iterative nature of LCA methodology). This means that one of the most significant issue on which further research work should be focused on, is the availability of LCI data especially for some kind of processes for which there is still a lack of complete and reliable data, as more extensively treated in Section 2.4.4.

2.4.4 Quality of data

Data availability and data quality is one of the main problems of LCAs applied in the agri-food industry; with particular reference to the olive oil sector, the above mentioned literature review and critical comparative analysis, revealed that there is still a lack of complete and reliable data for many kind of processes differently located in the various life cycle phases.

As in other agri-food productions (Notarnicola et al. 2012), also in the olive oil one, most of the problems also concerns specifically the agricultural step. Hence this phase is often partially assessed because of different reasons almost always linked to the unavailability of data, such as:

- the production of some specific kind of fertilisers, herbicides and pesticides – this problem is usually tackled excluding the production of these inputs or including the production of a generic fertiliser/herbicide/pesticide (present in the available databases), by entering the quantitative data on the effective consumption of the input weighted according to the active ingredient of the fertiliser/herbicide/pesticide in the database;
- the dispersion of compounds into the environment (air, water and soil) deriving from the use of fertilisers, herbicides and pesticides – this problem is usually tackled excluding these emissions or estimating them using specific model of dispersion, such as the Brentrup model for fertilisers dispersion, and the successive enhancements of the PestLCI model (Hauschild 2000; Birkved and Hauschild 2006; Dijkman et al. 2012) for pesticides dispersion. In general, the direct emissions from chemicals should be more stressed in environmental assessments of the cultivation phase, but few times they are included into calculation. It is also important to underline that a more complete database on chemicals should lead to a more "realistic" evaluation of potential impacts;
- the balance of CO_2 emissions - this calculation is generally omitted (thus implicitly considering the carbon balance as net zero), even if, more recently, a number of studies have begun to include the carbon balance in the boundaries, but, due to a lack of specific data and of characterisation methods, generic data collected from commercial and free database or estimations from literature was used (Sofo et al. 2005; Carvalho et al. 2012; Nardino et al. 2013; Iraldo et al. 2013; Palese et al. 2013); it should be highlighted the also the CO_2 absorbed by the plants during their vegetative cycle (the age of plants play an important rule) should be taken into account.
- the emissions from the use of agricultural machinery – these emissions may also significantly change based on the type of machinery, the type of work, and the type of ground, but due to insufficient or uncertain data only the emissions deriving from fuel consumption are generally included;
- use of pruning residues as natural fertilizers – frequently also the destination of pruning residues should be included, because they are often used as fertilizer or for domestic heating, bringing significant benefits for certain impact categories;
- plant breeding and tree planting – few studies include the establishment of olive grove generally because they consider new cultivation with young trees; furthermore the PCR "virgin olive oil and its fractions" of the International EPD System® specify to include this process only "if the olive grove life time is expected to be less than 25 years" but, even if the PCR do not mention it, in

this case~~ it should be noted the~~ maybe also the end-life of the olive groves should be considered,

- double counting and incorrect attributions – when collecting primary data in agricultural firm that produces mainly olives/olive oil (with or without private mill), generally data related to different processes (mechanical processing of the soil, phytosanitary treatments, canopy management, fertilization, etc.) will be available and often detailed and precise, however, if the company has many cultivars, special care should be paid to report all data obtained at the FU choice, thus avoiding double counting and incorrect attributions.

Concerning the other life cycle phases problems of data quality and availability may occur in the olive oil extraction phase (e.g. because in the commonly available data sources many of the involved industrial processes are lacking so that emissions are only related to energy consumption), and above all in the waste treatment phase that is still lacking of relevant data for many processes that characterise the olive oil production supply chain, such as for example the combustion of olive pomace and pits, the quality characteristics of pomace compost and of the different types of pomace, emissions from composting activities, emissions from combustion of exhausted pomace, emissions from spreading of OMW on soil, etc. for example, OMW are significantly potential pollutant (high phytotoxicity, see Roig et al. 2006) but also contain valuable substances such as nutrients that could be reused in cropland and avoid the negative effects; the OMW should be considered as a new raw material necessary to make a new product and it should be valorised in LCA studies.

In the case of a cooperative oil mill. In this case, the choice of the FU becomes critical and it must chosen especially in relation to the availability of data. The collection of primary data related to the agricultural phase is the bottleneck of the whole study, because the correct assignment of each data to the functional unit must be assessed with extreme caution. The large number of best owers associates, the variety of cultivars, the variety of all the management operations of the olive grove are the variables that need to be taken into account when it comes to choosing the functional unit. If there are doubts about the availability of correct data related to a single cultivar, the FU also has to be defined on the basis of this variable. The same consideration must be made as regards to the phase of oil extraction. The variability of the oil and water content, the kneading timeframes and other factors that affect the extraction process, should be considered for the choice of the FU. The possibility of measuring the energy and heat consumption of the extraction system and of linking this data to the FU in a precise manner should be taken into account in any revision of the FU.

While issues related to the agricultural phase are often common to other food products, and therefore probably already discussed within covered by interest of the scientific community, the issues related to the waste treatment of this sector (primary for pomace and wastewater) are more specific to this area and inevitably more attention is necessary for this aspect. Qualche suggerimento/best practice a proposito?

Generally little attention is also put on the transport phase. EU produces over 70% of the world's olive oil, and the most important countries that import the product are USA, Brazil and Japan. In this respect the question arises: is it best to produce the most environmentally effective olive oils with low impact and transport them for thousands of kilometers or is it best to produce olive oils with conventional impacts and consumed locally? Therefore the transport phase of the packaged final product, to the market or to the consumer, should be more frequently included in the assessment.

Another aspect generally not considered in LCA studies for reasons of data lacking, is human labour that in the olive oil production sector is a fundamental input. It plays a primary role especially for what concern traditional and organic systems, in soil themanagement, pruning and harvesting phases. In this direction it could be important to integrate other methodologies (e.g. emergy evaluation) with LCA in order to have a more complete and coherent view on un-sustainability of systems. For example, the combination of macroeconomic analysis and LCA may prove to be particular useful since, compared to detailed life-cycle inventories, many models of entire economics employ a much smaller number of categories for representing production and consumption activities (Settanni et al. 2010).

The joint use of more than one indicator should provide a full sustainability diagnosis (Bastianoni et al. 2013), therefore it is very important to highlight outcomes obtained also through other methodologies, different from LCA. For example, EF could be an effective and immediate tool to communicate how much agricultural and transformation practices in the olive oil sector go beyond ecological limits and how to manage and use available resources in a sustainable way.

In general terms, it can be suggested to use literature data for the background system and plant/fields specific data for the foreground. High quality data are the basis of any high quality product environmental assessments. According to ISO 14044, the dimensions of data quality are: time-related coverage, geographical coverage, technology coverage, precision, completeness, consistency, reproducibility, source of data and uncertainty of the information. Preference should be given to primary and secondary data which are compliant with the ILCD Data Network entry level requirements (EC 2012). Secondary data should be country-specific. To assess data quality, the PEF data quality indicator (EC 2013) should be used. Data and calculations need to be transparent, enabling external peer reviews. Estimations are very frequently not accurate; therefore, if it is possible, they should be avoided, even if it could cause the exclusion of phases from the system boundaries. Also assumptions, due to the lacking of data, should be clearly declared because they often cause high variability and incomparability among different case studies.

Moreover results should be presented disaggregated as much as possible to facilitate comparisons and to better understand which inputs/processes are included (e.g. packaging materials, with or without transport and so on). However, starting from the assumption that missing data should not be ignored (unless they are within the defined cut-off criteria), when data gaps are filled with similar or estimated data (using data of analogous processes or materials or using estimation and/or characterisation methods, etc.), data quality checks should be made in order to increase the value of LCA findings for decision making or comparative assertions.

Finally, by considering the site-specific characteristics of agricultural activities (in contrast with the site-independent nature of LCA methodology) (Notarnicola et al. 2012, Salomone and Ioppolo 2012) and the variability of data in this specific sector (stressed in Notarnicola et al. 2013), a consistency check of data quality should be in any case carried out.

2.4.5 Allocation methods

Following the ISO requirements (ISO 14044:2006, 4.3.4) whenever possible, allocation should be avoided by dividing the unit process to be allocated into two or more sub-processes or expanding the product system. In this case, in the olive oil production the most common solutions cited by authors were the expansion of system boundaries in order to include the process connected to by-product treatment and calculate the advantage obtained from the avoided product or the application. The most common solutions cited by authors were the expansion of system boundaries in order to include the process and calculate the advantage obtained from the avoided product or the application of allocation using different methods coherently with the scope of the analysis.

When allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system. Whenever it is unclear if allocation based on underlying physical relationships is appropriate, economic allocation shall be performed as a sensitivity analysis.

But, the allocation procedures in the olive oil sector should take into account that systems of this sector are characterised by one main product (olive oil) of generally high quality and thus high value, and a large quantity of low value by-products (pomace, OMW) that can be used as fuel and/or composting purposes, this means that an allocation by using only the mass quantities or only the economic value could be misleading. Indeed, the allocation procedure should take into account both the mass and the economic value of the by-products (a weighting between mass and economic value should be needed in order to balance the quantities of by-products obtained with their low economic value).

2.4.6 Life Cycle Impact Assessment (LCIA)

The impact assessment, should be carefully planned to achieve the goal and scope of the study, by choosing coherently the impact categories, and carrying out the classification and characterisation, and if necessary, the grouping and weighting. As far as the choice of the mid-point and end-point impact categories, there are many evaluation methods which allow highlighting environmental performance in the olive oil chain.

Also the way in which the results are shown can underline particular aspects of the environmental assessment. Percentage results, for example, could be shown in order to highlight the contribution of the sub-phases to the total environmental impact; or, in alternative, after the grouping and weighting phase, the contribution of each impact category. The absolute values are useful in order to quantify in a simply and understandable way the results for each impact category.

In a LCA study of the olive oil chain, the consumption of water, energy and other resources should be indicated, and the following emissions should be considered: greenhouse gases; ozone-depleting gases; acidification gases; gases that contribute to the creation of ground level ozone; emission of substances to water contributing to oxygen depletion; emission linked to the human and eco toxicity. Other impact categories that should be evaluated due to their importance in the olive oil sector are land use, and water used.

Beyond the impact indicators, inventory data can provide information about the assessed product environmental performance. The use of energy, divided by the energy source, can be established as an indicator if considered significant. Water use should be assessed as part of the resource depletion category and, given its importance for the olive oil sector, in particular the in agricultural step, the water use indicator shall be reported separately from other resource use indicators.

Together with data availability and data quality, Life Cycle Impact Assessment (LCIA) is the other issue in which the major LCA methodological problems occur. The main reasons are linked to the fact that standardised and universally accepted impact assessment methodologies for some impact categories are still lacking or at least require further refinements and improvements to consistently measure the environmental problems which are intended to represent. This is, for example, the case of land use for which it is actually not possible to perform a complete assessment of all impacts to it connected (essentially for lack of data); land use is at the moment assessed using few key impacts and for a complete assessment further research is necessary to face the unresolved problems.

Also water use impact assessment, of more recent interest in LCA respect to land use, need improvements in environmental assessment scheme. Water use is growingly considered important as climate change and different assessment methods began to be developed, but improved inventory data and agreement on which LCIA methods should be used for the assessment of relevant aspects have to be determined.

In general, it can be observed that problems of LCIA for olive oil production coincide with those of the wider agri-food sector and therefore the same considerations expressed in Chapter 1 and in the other chapters on the further agri-food chain analysed in this book are of interest for the olive oil production sector.

2.4.7 Interpretation

By following the ISO standards, an interpretation phase should identify the significant issues, and evaluate the strength and consistency of the results.

In the olive oil sector, considering the unresolved problems previous mentioned, partly specific of this production and partly common with the general agri-food sector, in order to obtain a reliable and consistent interpretation of the LCA results, sensitivity checks on uncertain data and on "sensitive" methodological choices should be performed.

For the olive oil sector, uncertain data and "sensitive" methodological choices could be:

- the choice of the functional unit;
- the production of some specific kind of fertilisers, herbicides and pesticides;
- the dispersion of compounds into the environment (air, water and soil) deriving from the use of fertilisers, herbicides and pesticides;
- the balance of CO_2 emissions;
- the emissions from the use of agricultural machinery;
- data concerning many waste/by product treatment;
- allocation methods;
- some impact methods (such as land use and water use);
- ………altro che si dovrebbe aggiungere???………;
- and all the other data of uncertain source or of estimation nature.

2.4.8 Critical review

In order to assess the scientific and technical validity of the study and improve the credibility of the study, a critical review could be carried out by an external independent expert.

The performed analysis put in evidence that CR of experts is still rarely practiced (maybe for the required additional costs), and only organisations working with environmental labeling or product declarations push themselves to demonstrate the quality of their LCA results with a CR. For these reasons, a critical review by independent experts should be practiced for each LCA study, on one hand to reduce the variability and subjectivity and, on the other hand, instead, to increase the credibility (e.g. ISO/DTS 14071:2013 working draft).

The role of expert review is also essential for reducing errors and uncertainty in LCA data, so that new solutions to encourage a greater use of external reviews should be found: the future ISO 14071 should find solutions in this direction.

2.5 Conclusions

The critical comparative analysis allows highlighting some general hot-spots of the olive and olive oil supply-chain:

- when comparing different kinds of vegetable oil - olive oil resulted more eco-compatible than sunflower seed oil for all categories except for land use, and for both systems the most impacting phase is the agricultural one (Nicoletti et al 2001);
- when performing a cradle-to-gate or a cradle-to-grave LCA analysis - the agricultural phase results as the most impacting one in almost all the impact categories (Salomone 2002; Avraamides and Fatta 2008; Christodoulopoulou et al. 2011; Testa et al. 2012; Iraldo et al. 2013);
- when focusing on the cultivation phase – environmental impacts of this phase are mainly due to the use of fertilisers that cause that eutrophication and acidification (Nicoletti and Notarnicola 2000; Salomone 2002), but also the use of pesticides and land-use in the conventional olives cultivation (Olivieri et al. 2005b; Olivieri et al. 2007a). Considering different practices, it can be observed that the irrigation systems is more eco-compatible than the dry ones thanks to its higher olive productivity (Nicoletti and Notarnicola 2000) and conventional scenarios highlight higher environmental loads than the organic (except for impact categories associated to land use) (Olivieri et al. 2005a; Olivieri et al. 2005b; Salomone et al. 2010a; Salomone and Ioppolo 2012);
- when focusing on the olive oil extraction phase – even if the agricultural stage is more significant when compared to processing stage, the processing stage is of primary importance when it comes to groundwater contamination, mainly due to the particular management practice of effluent disposal to evaporation ponds (Avraamides and Fatta 2008). Considering the different olive oil extraction methods and their by-product treatments, the double pressure system resulted more effective than single pressure and centrifugation (Nicoletti and Notarnicola 2000), and even with a wider scenario analysis the most eco-compatible production chain is the one that uses a continuous two phase transformation (De Gennaro et al. 2005);
- when focusing on olive mill by-product treatment - significant positive contributions are obtained, in terms of environmental credits for avoided production, associated with the use of by-products as fuels or fertilisers and different ex-

amples are analysed in the studies, eg.: olive mill waste water recovery as fertiliser (Testa et al. 2012); energetic exploitation of pomace stone (Cini et al. 2008) and recovery of olive pit used as fuels (Russo et al. 2008); co-composting of OWP with manure on fields or co-composting of OMW and OWP with composter machines (Salomone and Ioppolo, 2012); etc.

The analysis also 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. Thus, how to design a more efficient and environmentally friendly local olive oil production chain? and how to use LCA as a chain-focused management tool?

In order to develop LCA as a useful predictive tool for restructuring supply chains with the aim of improving their environmental performance, lessons learned allow to highlight that in this sector research is needed to increase the credibility of existing LCA data and the priority is the improvement and expansion of databases for these substances; however, models that estimate their dispersion in water, air and soil must also be simplified. Despite these limitations, this study can help us to better understand how useful the LCA methodology can be in the decision-making process connected to the definition of an environmental chain strategy and it certainly stresses the main gaps in current knowledge on which future research and developments should be concentrated. But the olive oil chain should not beinterpreted as a 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, and LCA should be used as a starting point for the continuous improvement procedure with regard to the environment, identifying inputs, processes or phases with the most significant potential impacts, and considering measures for their control.

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