Chapter 2
Life Cycle Assessment in the Olive Oil Sector

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Abstract 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 different procedures, olive oil production is associated with several adverse effects on the environment, both in the agricultural and in the olive oil production phase. As a consequence, tools such as LCA are becoming increasingly important for this type of industry. Following 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, as well as briefly describing other life cycle thinking methodologies and tools (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 analysed in depth, 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 LCA in the olive oil production sector are proposed.

Keywords Olive oil · Life cycle assessment · Life cycle costing · Environmental product declaration · Footprint labels

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2.1 Introduction

Olive oil production is an important agri-industrial sector (in terms of both production and consumption) in many Mediterranean regions (IOC 2013; Vossen 2007). Furthermore, the olive groves and olive production are increasing yearly (FAOSTAT 2013) and, recently, the importance of olive oil has also been growing in new producing countries located in America, Africa and Australia (IOC 2013). On a global scale, most olive cultivation areas[1] can be found in Mediterranean countries, such as Spain (2,503,675 ha), Italy (1,144,422 ha), Tunisia (1,779,947 ha), Greece (850,000 ha), etc. (FAOSTAT 2013). The leader of the international market is the EU, which produces over 70 % of the world's olive oil. As concerns importing countries, the most important are the USA, Japan, etc. With regard to exports, the most relevant are the main EU countries, exporting over 440,000 t of olive oil, followed by Tunisia, Syria and others (Table 2.1).

Despite the economic importance of this food product in many countries, olive oil production is associated with several adverse effects on the environment that cause resource depletion, land degradation, air emissions and waste generation. The 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 gain a better understanding of their role from a life cycle perspective.

In the following sections, these different practices and techniques, along with the relative environmental consequences, are briefly described (Sect. 2.2). Then, a description of the international state of the art of life cycle thinking methodologies and tools, suitable for the environmental assessment of products and implemented in this specific sector, is presented (Sect. 2.3), with a specific focus on life cycle

[1] Data for the year 2011.

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Table 2.1 The olive oil market on the international scale (the average values of the 2007/2008–2012/2013 olive crop six-year period). (Source: Data (IOC 2013))

Country	Production (1000 t)	Imports (1000 t)	Exports (1000 t)	Consumption (1000 t)
EU[a]	2057.6	111.9	447.1	1819.3
Spain	1215.1	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
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

[a] The import and export data of the EU countries are reported without intra-Community trade

assessment (LCA). The methodological problems connected with the application of LCA in the olive oil production sector are analysed in depth, starting from a critical comparative analysis of the applicative LCA case studies in the olive oil production supply chain (Sect. 2.4). Finally, guidelines for the implementation of LCA in this sector are proposed (Sect. 2.5), in order to deal with and manage best the methodological problems presented above.

2.2 The Olive Oil Supply Chain: Production Processes, Technologies, Product Characteristics and Main Environmental Problems

A supply chain is a 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 (IOC 2013; Niaounakis and Halvadakis 2006; PROSODOL 2011), 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 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;
- the cultivation practices are conventional, organic or integrated, using different typologies of fertilisers and pest treatments;
- the soil management, pruning and harvesting are manual or mechanised.

Harvesting is a very important process, because changes in the acidity level of olives occur after harvesting and other changes occur depending on the harvest methods: hand harvesting is the best method, but very expensive, while mechanical harvesting, if properly conducted (avoiding the breaking of the fruit skin), can give good results. After harvesting, the olives are sent to olive oil mills and processed within 24 h, 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 as the first type together with an increase in the tree density and the weed control, soil management using artificial fertilisers and irrigation, the use of pesticides and mechanical harvesting); and intensive modern plantations (high small-tree density managed with extensive use of mechanised systems and irrigation). The low-input traditional plantations have the lowest environmental impact and, moreover, they play a role

[2] Some of these treatments and practices are managed similarly to other fruit cultivation (see Chap. 6).

in safeguarding the 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 waste. The waste stream is highly hazardous to the environment and presents a number of treatment challenges to olive oil producers.

The ***olive oil production phase*** includes two main phases: the preparation of a homogeneous paste and the oil extraction from the olives. First, the olives are classified and separated by quality; then, they are washed in order to remove the pesticides, dirt and impurities collected during harvesting (stems, leaves, twigs, etc.). A few olive oil mills do not wash olives, which are processed 'as they are' to overcome the problems connected with water consumption and the treatment of the polluted washing water. This is often motivated by the fact that extra moisture can involve problems (extractability and lower polyphenol content). 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 the olives and in the olive oil. After washing, crushing (tearing 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 of separating the oil from the rest of the olive components: oil is extracted using a press or a decanter, by pressing (the traditional or classical system) or by centrifugal separator (a continuous system), which can further use a three-phase or a two-phase decanter.

Traditional pressing (a discontinuous process) is still in use in some small mills that use a hydraulic press, but it is a relatively obsolete technology that has mainly been replaced with centrifugation systems, allowing 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, which is separated by decantation from the remaining wastewater.

Continuous centrifugation with a three-phase system, even though offering a higher production capacity with respect to traditional pressing, has some disadvantages, such as 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 solid waste (olive husk or olive pomace), olive oil and wastewater.

Continuous centrifugation with a two-phase system allows the separation of oil from olive paste without the addition of water and this leads to the elimination of the problem of vegetable water. In fact, the two-phase system 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 a modified system or water-saving system) exists; 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 *oil extraction from de-stoned olives*. In the de-stoning process, the pits are removed before the kneading; some authors state that this process improves 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 2010) believe that this technology produces lower yields with a similar chemical sensory quality. Oil extraction from de-stoned olives can be made with both the three-phase and the two-phase system.

On average, 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 was equal to 2,862,800 t (IOC 2013), on the basis of the 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 as the olive oil obtained from the fruit of the olive tree by mechanical or other physical means under conditions, particularly thermal conditions, that do not lead to alterations in the oil, which has not undergone any treatment other than washing, decantation, centrifugation and filtration, excluding oil obtained using solvents or re-esterification processes and any mixture with oils of other kinds (EC 1991, 2007, 2008, 2013a). In particular, in accordance with the standards of the International Olive Council (IOC n. d.) and the EC regulations, *virgin olive oils* are classified into:

- *extra virgin olive oil*, which is a higher quality olive oil with no more than 0.8 g per 100 g 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 (lower than 30 °C);
- *virgin olive oil*, which has no more than 2 g per 100 g of free acidity and a good taste;
- *lampante olive oil*, which is virgin olive oil with 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 use.

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

- *refined olive oil*, obtained by the refining of virgin olive oil using methods that do not lead to alterations in the initial glyceridic structure; it has no more than 0.3 g per 100 g of free acidity;
- *olive oil*, which is a blend of refined oil and virgin oil (excluding the lampante virgin oil), fit for consumption as it is and having no more than 1 g per 100 g 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*, which is obtained from crude olive pomace oil by refining methods, producing an oil with no more than 0.3 g per 100 g of free acidity.

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

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 containing mineral salts, sugars and polyphenols (EC 2010). To extract pomace oil from the traditional and three-phase production methods, solvents are used. The olive pomace is mixed with the solvent hexane, which 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 (then captured for reuse). The oil and hexane solution is distilled, allowing the hexane to be recovered and reused, whilst the solvent-free oil undergoes further processing, such as refining. The solid waste from olive oil mills is also referred to as 'olive cake' and the liquid waste streams are termed olive mill wastewater. In recent years, the by-product management has been 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 options have been proposed for their treatment, disposal or valorisation (Niaounakis and Halvadakis 2006; Roig et al. 2006; Vlyssides et al. 2004):

- Olive mill wastewater (OMW), deriving from traditional pressing and from the three-phase system, is the main polluting mill waste. This is constituted by vegetable water from the olives and the water used in the oil extraction and its chemical composition is variable depending on the olive varieties, growing practices, harvesting period and oil extraction technology. In any case, it is highly polluting due to the presence of organic compounds (organic acids, lipids, alcohols and polyphenols), even though it also contains 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 colouring natural waters, altering soil quality, phytotoxicity and odour 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 (Di Giovacchino 2010; EC 2010). The olive mill wastewater levels from three-phase processes are much higher, producing between 800 and 1000 L 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 that 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 the 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 the climatic and soil conditions, farm management, harvesting methods and oil extraction processes. The presence of proteins, minerals and polysaccharides in OMW means that it has potential for use as a fertiliser and in irrigation. However, the reuse opportunities are restricted by the abundance of phenolic compounds, which are both antimicrobial and phytotoxic. These phenols are difficult to purify and do not respond well to conventional degradation using bacteria-based techniques. The 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 mg per litre. This represents a notably large organic matter load compared with standard municipal wastewater, which exhibits levels between 400 and 800 mg per litre. Anaerobic digestion of *alpechin* results in only 80–90 % 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 the 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. The 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 (plants–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 the humans and animals coming 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 of in landfill sites or used as a fertiliser in agriculture (after a composting process with other agricultural by-products);
b. direct application to soil—this is a positive valorisation method of OMW considering its high nutrient content and its high antimicrobial capacity, but it also causes negative effects on soil associated with its high mineral salt content, low pH and presence of polyphenols. Land spreading of waste arising from olive processing is specifically regulated by law (e.g. in Italy by the Ministerial Decree—MIPAF 2005);
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 avoids the negative effects previously cited when OMW is directly applied to soil (Cappelletti and Nicoletti 2006; Salomone and Ioppolo 2012);
d. the 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, as the recovery process is of economic and practical interest (Fernández-Bolaños et al. 2006).

- Olive husk (OH), deriving from traditional pressing and from the 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*, which is used as fuel since the dried OH presents high calorific power.
- Olive wet husk (OWH) derives from the two-phase system. In this case, olive vegetation waters are included in the OWH. Compared with the OH, the higher moisture level in the OWH creates more difficulties for its treatment in oil factories (mainly the higher energy demand for the drying process causing higher costs). For this reason, there are other methods for the treatment of the OWH and the most common are:

    1. Direct application to soil—due to its high potassium concentration and its low economic value, it can be directly applied to soil on land near the production site, but this practice could cause a negative effect on the soil even if it is less phytotoxic than wastewater (Cichelli and Cappelletti 2007);
    2. Composting (with or without the de-stoning process to obtain biomass for heat or electricity)—this method consists of the co-composting of OWH with other agricultural wastes (straw, leaves, etc.) or with manure used as a bulking agent. 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 ***packaging phase*** includes bottling olive oil in glass, tin or PET containers. As the average annual world consumption of olive oil in the 2007/2008–2012/2013 olive crop six-year period was 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 amount to more than 2,860,000,000 per year.

The ***transportation and distribution phase*** includes the transport activities (related to raw materials, by-products and wastes) and the distribution of the product in local, regional, national or international markets. Transport activities can also occur elsewhere in the life cycle (other than those instances 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 olive oil, is certainly not significant from a life cycle perspective, considering that the product consumption does not need further preparation or treatments. Table 2.1 shows that the consumption of olive oil is quite widespread on the international scale in countries such as Italy, Spain, the USA, Greece, Turkey, Syria, etc.

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

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

As far as the materials and energy balance related to the oil production are concerned, it is possible to highlight that the production (agricultural and industrial phases) of 1 kg of olive oil (double pressed) involves the consumption of 0.0264 kg of fertilisers (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).

2.3 Life Cycle Thinking Approaches in the Olive Oil Production Sector: The State of the Art of the International Practices

As exhaustively reported in Chap. 1, the growing awareness of food sustainability is driving an increase in research activities in the agri-food sector and, among these studies, over the last 15 years or more, numerous life cycle thinking (LCT) approaches have been followed (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 the 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 2008) and then updated in 2010 (Salomone et al. 2010a), but contained only a comparative analysis of Italian studies, with the aim of highlighting the features of and/or differences in the fundamental aspects of Italian LCA studies; the first review included 13 Italian LCA case studies, while the second one contained 23 case studies. On the contrary, the literature review presented in this paragraph is a wider and deeper analysis with respect to the previous ones, because it includes:

- international case studies, not only Italian ones;
- life cycle thinking tools, not only LCA ones;
- 'olive industry' case studies, not only olive oil ones.

In particular, this literature review includes LCA studies that directly or indirectly refer to the wider term '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 simplified LCA (S-LCA), 9 dealt with environmental footprints (the carbon, water or ecological footprint) or energy balance or analysis and carbon balance, 10 were EPDs (Environmental Product Declarations) or papers reporting on EPDs and 2 reported on the integrated use of LCA and multi-criteria analysis (MCA).

In the following, a state-of-the-art analysis of the literature on life cycle thinking studies implemented in 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 labels, EPD, etc.).

2.3.1 Life Cycle Assessment

The literature review shows that the most-used LCA analysis applied in the olive oil sector presents 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 combination 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 Busset et al. 2012; De Gennaro et al. 2005; Salomone and Ioppolo 2012; Salomone et al. 2010a), 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) analysed various processes of the olive oil production chain, combining different oil extraction methods of extra virgin olive oil and different disposal and/or

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 (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
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 (n.d.)	✓		Olive oil
Intini et al. (2011)	✓	CF	Olive oil mill waste
Nicoletti et al. (2011)	✓	EPD	Olive oil

Table 2.2 (continued)

Reference	LCA	Other tools	Product
Özilgena and Sorgüven (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
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. (2013a)	✓	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

reuse treatments of pomace and other olive oil mill waste. The analysis indicates as the most eco-compatible production chain the one that uses 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 the ground of the oil mill waste water. In Salomone and Ioppolo (2012) and Salomone et al. (2010a), comparisons of eight different scenarios, including different combinations of cultivation practices,

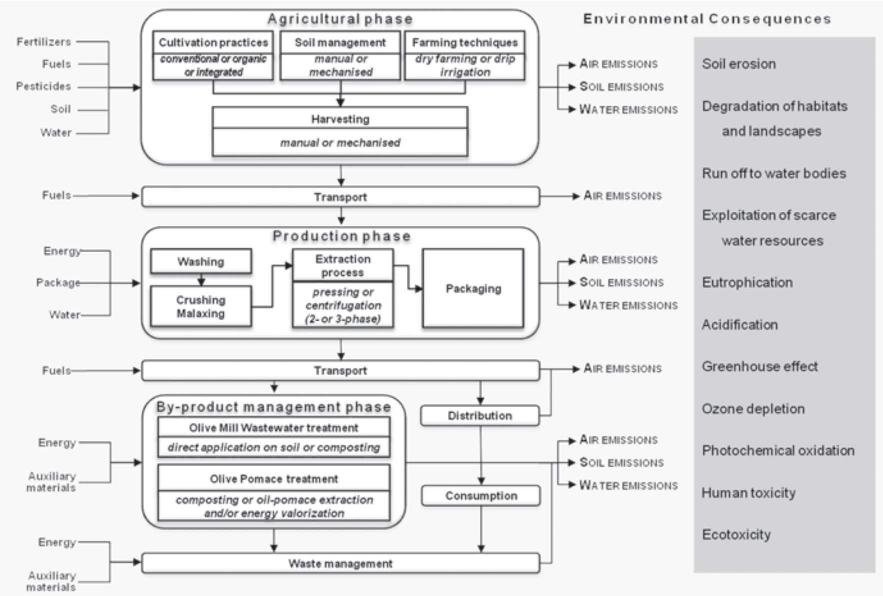

Fig. 2.1 The olive oil supply chain and its main environmental consequences

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 with land use), an important environmental load associated with some sub-processes (such as fertilisation, the use of pesticides and the 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 co-composting olive mill wastewater (OMW) and OWP with 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 cultivation techniques, the different extraction processes and the different kinds of waste. Another paper, by Cavallaro and Salomone (2010), has a similar structure but provides new insights, because the LCA was implemented with MCA (see Sect. 2.3.6).

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 the categories except land use. The phase with the greatest impact 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 the VOC emissions occurring during sunflower oil chemical extraction. Another scientific article presents a comparison of olive oil with other kinds of vegetable oil (Özilgen and Sorgüven 2011), but it conducts an energy analysis rather than an LCA study (see Sect. 2.3.4).

Other comparative LCA studies focus on specific life cycle steps. For example, Russo et al. (2009) focused on the comparison of two processes of production of extra virgin olive oil using whole or de-stoned olives. The two processes present similar environmental performances, even though the process in which de-stoned olives are used has a lower impact: the real advantage of the de-pitting process is to obtain fragments of olive stone, which is an important by-product (much appreciated as fuel) both from an environmental and from an economic point of view. Similarly, Romani et al. (2004) focused on specific life cycle steps but reported on two diverse LCA applications: a comparison of organic and conventional virgin oil production and a comparison of two different applications for olive oil mill wastewater. The comparison of organic and conventional olive oil production is an aspect that had already been investigated by integrating the LCA and LCC methodologies (see Sect. 2.3.2), and other studies have been performed to compare these 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 organic production, the impacts are related to a huge amount of fuel consumption (because of the use of old and low-efficiency machinery), whereas in conventional production, the main impacting input is the use of chemicals.

Olivieri et al. (2005a, b) applied LCA with a particular focus on the olive cultivation phase, for both conventional and organic farming, with the aim of quantifying numerically the environmental damage of the olive cultivation process and estimating the opportunities to reduce the impacts by comparison with organic olive cultivation (sensitivity analysis). Generally, these studies highlight higher impacts of conventional cultivation (except for the land use impact category). The other LCA presented by Romani et al. (2004), entailing the comparison of different wastewater treatments, falls into another widespread kind of LCA analysis that refers to waste treatment. Indeed, in 2002, the first LCA application not focusing on olive oil but on one of the main olive oil mill wastes (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 that 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 focusing on olive oil mill waste were published and/or presented, such as the following studies:

- In Romani et al. (2004), a comparison of two different uses for olive mill wastewater (fertilisation–irrigation and optimised purified procedures able to recover higher quantities of polyphenols in view of possible future industrial application) is presented: a lower environmental load for the treatment allowing the recovery of polyphenols is highlighted;

- In Russo et al. (2008), an analysis of the environmental advantage deriving from the use of olive pits as fuel (by combustion in furnaces commonly fed with wood pellets or de-oiled pomace), comparing the environmental impact with that generated by the recovery of de-oiled pomace and the production of wood pellets, was performed. The results show that the recovery of olive pits 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, b), an LCA study applied to a new integrated technology for olive oil mill wastewater (OMW) treatment and polyphenols recovery from a biphasic olive mill is presented. This method treats olive oil wastewater and, at the same time, produces novel products exploiting the antioxidant properties of polyphenols as a semi-manufactured good for 'novel food' (e.g. phytotherapy, cosmetics). The results of a sensitivity analysis show that the LCA of this process has less impact, with an overall percentage of 57 % with respect to the 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 'novel food'. Moreover, the recovery of polyphenols helps to avoid phytotoxicity in soil;
- Intini et al. (2012) carried out an LCA in order to compare the environmental performance of using de-oiled pomace and waste wood as fuel. Only the global warming potential was 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 the reduction of greenhouse gas emissions;
- 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 the atmosphere. The environmental impacts of all three treatments show that human health is primarily affected, followed by impacts on resource 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), were compared and the results show that all the 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 to be the best option, from both an environmental and a technical point of view, while the chloroform/isopropyl alcohol mixture was found to impose detrimental effects on 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 the cultivation of olives, olive oil production, olive husk treatment and transport between these treatment phases. This was the first study to include pomace treatment in the LCA analysis of the product ‘olive oil’. The motivation was to avoid allocation, as suggested by ISO 14044 (at the time of the research ISO 14041), expanding the system in order to include the treatment of this by-product of olive oil production as well. 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 and Ioppolo 2012; Salomone et al. 2010a), 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-product treatment and valorisation). Furthermore, in Cini et al. (2008), LCA was used 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, just taking into account the extraction process of olive oil following different methods: the extraction process with oil production and pomace treated as waste; the extraction process with oil production and pomace used as a fertiliser; the extraction process with oil and pomace stone production; the extraction process with oil and pomace stone production; and the use of pomace residue as a fertiliser.

In 2007, table olive production also started to be investigated, mainly because of the growing interest in this specific sector caused by the increase in their cultivation and processing activities, as well as the relevant amount of wastes generated by the connected processing industries. Different papers have analysed this particular kind of production and its various aspects in depth: green olive cultivation and olive processing using the Spanish-style method (Cappelletti et al. 2010; Nicoletti et al. 2007a); black olive cultivation and olive processing using the Californian-style method (Cappelletti et al. 2008); a comparison of three different methods used for processing ripe table olives—two different methods of the Californian-style and the Spanish-style method (Russo et al. 2010, 2012); a comparison of the different packaging systems (Nicoletti et al. 2007b); and a study (Cappelletti et al. 2011) focusing on the production processes, the characteristics of wastewater and the pollution prevention technologies (in this case, the LCA results underline that eutrophication is a very important impact for the table olive 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 was 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 the environmental flows considered was less than 0.5 %) in priority 4;
- Fiore et al. (2009)—in this paper, the 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 as well as the packaging phase, which involves an environmental impact due to the glass bottle production;
- Christodoulopoulou et al. (2011)—a comprehensive LCA was carried out on olive oil of extra virgin quality, produced from 487 olive groves by 3 groups of 68 olive growers in southern Greece. The first goal of the study was 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. The second goal was 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)—an 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 the waste management of the olive oil sector in the SUDOE area (Spain, Portugal and France). The first results permitted the definition of 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 in two phases or centrifugation in three phases) and the different waste management schemes (incineration or spreading). The expected result was a comparison of all the scenarios in order to identify the parameters that influence the 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 decisions 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 on 63 farms in the northern area of the city of Bari in Puglia (Italy), with the aim of assessing the variability of the LCA results. This is one of the few papers to analyse with the same inventory more than 60 data sets. The results indicate great variability within the management methods of the olive orchards, with agronomical practices differing from producer to producer (even from the same area). This is reflected in the high degree of variability of the inventory and impact assessment results.

Other interesting applications of the LCA methodology within the field of olive oil production include its use for supporting the definition of environmental management strategies and the integration of tools. In 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 for the acquisition of a territory product mark (Olivieri et al. 2007a, b, 2008). LCA was used to characterise environmental critical states in the cultivation and production of virgin oil; the most important problems identified are the use of fertilisers, the use of pesticides for olive fly capture and land use in conventional olive cultivation;
- The second one is the case of a study specifically focused on the design of a model of a Product-Oriented Environmental Management System (POEMS) for agri-food companies (Salomone et al. 2013a), which includes the use of the 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 with the PET bottle system, except for the fossil depletion category, in which the higher score is linked to the PET bottle system, caused by PET production;
- The third one is an LCA applied to the production of extra virgin olive oil in the Val di Cornia, Tuscany, Italy (Testa et al. 2012; Iraldo et al. 2013). The LCA study is intended to support the experimental implementation of a system of environmental qualification of a product, managed locally, which combines the features of type I and type III eco-labels. The agricultural phase is the most impactful of all the 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 a fertiliser and for domestic heating brings significant benefits for certain impact categories. In the extraction phase, olive mill waste water recovery as a fertiliser leads to a reduction in water consumption, eutrophication and global warming.

Another application of LCA presenting new insights is provided by Salomone et al. (2009), in which a comparison between a conventional extra virgin olive oil and a high-quality extra virgin olive oil with the characteristic of excellence is presented. The new element consists of an attempt to integrate the environmental impacts and the quality characteristics of the product into the LCA methodology by inserting an impact category called 'cardiovascular risk' defined on the basis of the contribution that the phenols, contained in olive oil, make to increasing HDL cholesterol (which helps to reduce cardiovascular risks); the aim of the study was to match the potential environmental impacts of the entire product life cycle with 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 n.d.), the OiLCA project in the SUDOE area (Spain, Portugal and France) (Busset et al. 2012), the EMAF project in Italy (Salomone et al. 2013b) and the Life+ECCELSA project in Val di Cornia, a rural area in the south of Tuscany, Italy (Iraldo et al. 2013).

2.3.2 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 to study the way in which materials and substances flow through the economy.

As far as the accounting for costs at the microeconomic level is concerned, although life cycle costing (LCC) is not as standardised, as LCA is, there is a significant body of literature that addresses its conceptual framework and methodology. Thus, applications to food products, being applications of more generalised concepts, might seem not to pose major methodological problems: there is, in fact, evidence that LCC is also being used as a decision support tool within the LCA of food products. However, the literature provides few applications of LCC to food products and, more generally, to non-durable products: in this sector, applications of traditional LCC make sense only if an investment in a 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 external costs, are expected to affect the ranking of alternative options heavily, 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 stated before, macroeconomic-oriented accounting tools, such as input–output tables, are used. Either they can be 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 particularly useful since, compared with detailed life cycle inventories, many models of entire economies 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, in 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 (Carvalho et al. 2012; De Gennaro et al. 2012; Notarnicola et al. 2003, 2004; Roselli et al. 2010), 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 reviewed in depth because three of them (Notarnicola et al. 2003; Pergola et al. 2013; Rosselli et al. 2010) are parts of other papers (respectively: Notarnicola et al. 2004; Palese et al. 2013; De Gennaro et al. 2012).

As with the LCA studies (see Sect. 2.3.1), 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 focus on Italian case studies (De Gennaro et al. 2012; Notarnicola et al. 2004; Palese et al. 2013; Pergola et al. 2013) and one on a European case study (Carvalho et al. 2012). Furthermore, just two papers focus 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 by Carvalho (2012) was developed within the OiLCA international project with the aim of improving the competitiveness of the olive SUDOE space (Spain, Portugal and the south of France) and 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 for 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 improving the quality of the final product. The management of these residues represents a big challenge because of their predominance and unavoidable production; it is thus important to take into account the available or emerging technologies, which may result in both economic and environmental benefits. The study was conducted by coupling the LCA and LCC methodologies, with 1 L of olive oil as the FU and the following phases as system boundaries: cultivation, oil production and packaging. Accordingly, it was possible to identify improvement solutions with their associated investment and production costs, providing business people with useful tools for making 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) aimed to compare the production systems of organic and conventional extra virgin olive

Table 2.3 Internal and external costs of the two systems (organic vs conventional) per functional unit (1 kg of extra virgin olive oil). (Source: Notarnicola et al. 2004)

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

oil in order to assess their environmental and cost profiles and to verify whether the two dimensions (environmental performance and costs) move in the same direction. For the cost assessment, in particular, the LCC methodology was applied with the same FU and system boundaries as 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. The transportation of chemicals (from the factories to the agricultural fields), of materials and of the 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 the use of fertilisers and pestidicides (in terms of reclamation and decontamination) costs more than 22 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).

Regarding the obtained outcomes, in the LCA–LCC comparison between conventional and 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, for example the ExternE project (ExternE 2013). As far as the LCA results are concerned, the study demonstrated that the organic olive system is more eco-compatible than the conventional one by a factor of five 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, 'high density' (HDO, over 200 tree/ha) and '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 an FU of 1 t of olives. The production of fertilisers and pesticides was also included, while transformation, distribution and consumption were excluded because they are 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 the higher initial investment costs that the company has to face (which result as three times those of the HDO system). Furthermore, the HDO model achieves better performance (in terms of NPV and IRR) than the SDHO model: this result is mainly driven by the lower plantation costs, longer production cycle, higher productivity of olives and greater efficiency in the use of inputs that characterise the HDO model. Furthermore, 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, this analysis also shows a better performance of the HDO system for all the impact categories (Global Warming Potential GWP, Ozone Depletion Potential ODP, Acidification Potential AP, Photochemical Ozone Creation Potential POCP, Human Toxicity Potential HTP, Freshwater Aquatic Ecotoxicity Potential FAETP, Marine Aquatic Ecotoxicity Potential MAETP, Terrestrial Ecotoxicity Potential TETP, Nutrification Potential NP, Abiotic Depletion Potential ADP), with a percentage ranging from 21 to 37 %. The superior performance of the HDO system is mainly linked to the lower use of energy but also to lower chemical inputs and higher olive yields. As far as the energy use is concerned, the full production phase is characterised by the highest energy consumption, with 87.4 % (HDO) and 75.1 % (SHDO). Finally, the study highlights that the 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) focuses on the proposal for a sustainable system (SS) for the management of olive orchards (156 plant ha^{-1} with a distance of about 8 m × 8 m) 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 to evaluate the sustainability of the proposed method when compared with the conventional management system (CS). In particular, the economic results were expressed at constant values by the formula:

$$\text{Gross Profit (GP)} = \text{Total Output (TO)} - \text{Production Costs (PC)}$$

with:

TO representing the income from sales of oil and table olives
PC showing 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 (€ 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, the TO of the SS was shown to be constantly positive and greater (about three times, mostly due to the higher quality of the olive production–table olives) than the CS value. Regarding the PC, the SS showed higher values than the CS. Both systems presented a positive value of the GP/ha, but the SS was four times more profitable than the CS. Finally, the SS produced quite a regular income over the considered period thanks to the annual yield, while the CS guaranteed a GP in alternative years. The environmental assessment was focused, above all, on the CO_2 stocks in plants and soil as well as the anthropogenic and natural CO_2 emissions. It demonstrates that from this point of view the SS system is the most sustainable as well. By comparing the mean annual fluxes of CO_2 (net primary productivity—NPP—total emissions), the SS system shows 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 that are higher than the 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, the 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 double). All that considered, the SS appears sustainable not only from the economic but also from the environmental and social points of view.

2.3.3 Simplified Life Cycle Assessment (S-LCA)

The practical use of environmental LCA methods and software tools in industry has revealed the need for simplifications of 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's, process's or service's life cycle (Hayashi et al. 2006). The aim of S-LCA is to provide, essentially, results that are the same as or similar to 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 the 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 undertake a thorough assessment of the reliability of the results. S-LCA studies can be conducted to make 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:

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

The 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.

In the olive oil production sector, LCA studies are, generally, aimed at identifying the environmental burdens associated with the processes involved 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. An S-LCA procedure can make possible studies based on information that is already available, e.g. at the early conceptual design stage or when the input data do not allow the assessment of sources of environmental burdens.

The scientific literature in the sector includes a few studies that specifically apply a simplified procedure. Among them, Abeliotis (2003) focused on the analysis of a three-phase olive oil mill. It is not a comparative analysis but it aimed to assess the greatest environmental burdens of the production system examined. In each production stage, the input and output streams of mass and energy were identified (inventory phase) and the environmental impacts associated with the process were 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 with the fertilisation of the olive trees and end with the extraction of olive oil. Region-specific and agricultural phase LCI data were 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 the literature were used. The data for the mass and energy balance at the extraction stage were derived from the examined production process, but no experimental data were available with regard to the organic load of the effluent olive mill wastes from the treatment step, the N_2O emissions and the energy embedded in fertilisers. Thus, these data were deduced from the literature sources and adapted to the analysed process.

This study shows that the most significant impact arising 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 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 an S-LCA study is presented in Raggi et al. (2000), in which the production and use of olive husk bricks, as a fuel for residential heating, were screened and a preliminary comparison of such a technology with natural gas combustion was carried out. The system boundaries were defined to cover all the steps from olive husk handling and pressing to its combustion in households, including the production of packaging and ancillary materials. The environmental burdens related to the oil extraction from olive cake were allocated in total to the extracted oil. With regard to the data quality, primary data were collected on-site directly from the economic factors involved in the product life cycle, while the literature and international databases were used for secondary data. The study presents a partial life cycle impact assessment, since only the GWP and AP were investigated. The results highlight that the most significant contribution to the GWP arises from transport, followed by the energy requirement in the husk-processing activities. No contribution of the CO_2 from the combustion of olive husk was considered, assuming it to be 'virtually' equal to the CO_2 absorbed by the plants during their vegetative cycle. With regard to the 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 a fuel in residential heating was compared with the performance of natural gas technology, with regard to the GWP and AP, in order to assess the environmental benefits and drawbacks associated with the biomass use, but the related primary energy saving was not considered. The assessed husk-based heating system contributes much less to the 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 evidences the need for higher quality data in order to avoid estimations, since many of them are missing or inaccurate, such as the emission factors of husk combustion.

In the two above-cited studies, the S-LCA procedure is applied as a 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 into 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 studies highlight the critical issues of the assessed production processes, such as the contribution to the GWP impact category, even though a more accurate analysis would also require the assessment of other impacts, such as the life cycle energy requirement in terms of primary energy, which is strictly connected to the GWP.

2.3.4 Footprint Labels (Carbon Footprint, Water Footprint, Ecological Footprint)

The term 'footprint' has become a popular means of indicating a quantitative measure of human beings' appropriation of natural resources (Hoekstra and Chapagain 2008). All three indicators, the carbon footprint, water footprint and ecological footprint, are aimed at evaluating environmental impacts in terms of the appropriation of natural resources needed to sustain the supply chain of a generic product. Specifically, the three indicators highlight the effect of resource consumption on different environmental compartments: air (in terms of greenhouse gas emissions), water (in terms of the 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).

In particular, the *carbon footprint* (CF) methodology 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 focuses 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 to standardise a similar methodology in 2013. Later on, the ISO published the international standard rules related to this method in May 2013—ISO/TS 14067:2013 (ISO 2013a). The unquestioned acceptance of the carbon footprint by retailers and the 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, the IOC (International Olive Council) is taking steps to draft guidelines for the correct and uniform application of the new ISO 14067. 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. 2010) focus on the analysis of the carbon footprint of 1 kg of olive oil (albeit only for the bottling stage): Nardino et al. (2013) carried out an empirical and tool-related assessment of the ability to fix the atmospheric carbon from the olive grove, while in Intini et al. (2011), a comparative evaluation of the use of de-oiled pomace, fossil fuels and wood biomass (in the operation of a power plant for the production of electricity and heat) was carried out. Polo et al. (2010) applied the carbon footprint methodology to five agro-industrial products, including two types of olive oil (1 L in glass bottles and 5 L in PET ones). The analysis shows that the CFPs are of 1.1 and 5.5 kg of CO_2 (respectively for bottles of 1 and 5 L). Furthermore, Özilgen and Sorgüven (2011) carried out an evaluation of three different methods (energy, exergy and carbon dioxide emissions) for three different oils (soybean, sunflower and olive) using 1000 kg of raw material product as a functional unit (soybean, sunflower and olive). In this study, the agricultural phase is responsible for most of the 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 is linked to the agricultural phase, 123.3 kg to the oil production phase, 31.9 kg to the packaging phase and 3.0 kg to the transportation phase.

Three 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 (Özilgen and Sorgüven 2011) was developed in Turkey, while the last, though not precisely defined, is believed to have been carried out in Spain.

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, do not use calculation software but use emission factors directly (published by government agencies and electricity producers). Furthermore, not all the GHGs provided by the IPCC are highlighted; only CO_2 and CH_4 are considered in the study. Intini et al. (2011) carried out an assessment of the benefits arising from the possible use of de-oiled pomace, for energy, taking into account both the current technologies that are already widespread and the nationwide availability of this product. The analysis shows the possible avoided emissions of GHGs if all the de-oiled pomace is destined not for residential users (as happens today) but for electricity and heat production plants. The analysis undertaken by Polo et al. (2010), although very interesting for the results achieved, does not show how the data collection was conducted and which software or database was used for the calculation of the carbon footprint. The study by Nardino et al. (2013), while making explicit reference to the carbon budget within an olive grove, does not use the specific methodology of the carbon footprint to assess the total mass of CO_2 stored. 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 is apparent that olive groves are useful for carbon storage and for biomass production destined for energy purposes (values between 10 and 15 t (C) ha^{-1} $year^{-1}$). In the study by Özilgen and Sorgüven (2011), the source of the emission coefficients and whether the study included all GHGs or just carbon dioxide were not clear. 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, due to both the small number of papers in the literature and the lack of comprehensive studies related to our subject of interest. The reasons for this refer to the recent standardisation of the method (ISO/TS 14067:2013 was published only in May 2013), to the scientific limitations of the tool, even though it allows strong communication, and to the fact that the olive oil sector, over the past 10 years, has invested more in improving the quality of the product (acidity, content of antioxidants, etc.) and in certification of origin (protected designation of origin PDO and protected geographical indication PGI), leaving out the communication of connected environmental aspects.

The *water footprint* (WF) is also to be noted, being a water use indicator that considers both the direct and the indirect content related to a process or good and referred to as the volume of fresh water used per unit of the product. It is divided into three components (Hoekstra and Chapagain 2008): the blue WF (blue water, surface or underground), the green WF (rainwater that is stored temporarily in the soil or vegetation) and the grey WF (the 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 analysing the WF of olives and olive oil produced in Spain. The analysis was conducted over several years (1997–2008) and on data aggregated at the provincial and national levels. It was found that the average value of the WF at the national level is: 8250 to 3470 L L^{-1} for the green WF (without irrigation), 2770 to 4640 L L^{-1} for the green WF (with irrigation), 1410 to 2760 L L^{-1} for the blue WF (with irrigation) and 710 to 1510 L L^{-1} for the grey WF. Since the relevant literature on this subject was found to be limited, no comparative evaluation can be undertaken 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 analysed system during 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 its 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, the EF provides a more differentiated and complete picture of the 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 from the original EF approach (Wackernagel et al. 2005) is that the Huijbregts approach considers product-specific yield factors applied to forestry, pasture and crops to obtain the direct land occupation instead of the global average yields (Ecoinvent Centre 2004).

Despite its diffusion and popularity, product EF applications are still scarce and, especially regarding the olive oil sector, there is no adequate background of case studies to highlight the appropriation of natural capital, the efficiency of natural resource use and the environmental pressure related to this sector. Indeed, up to now, studies focusing on the EF of olive oil production processes and phases by phase assessments have still not been 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 individual component. The only available data, obtained by using the original EF approach (Wackernagel et al. 2005), highlights the requirement for 905 g m^2 per capita for the annual consumption of 12 kg olive oil (75.4 g m^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 % is due 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.

Deeper studies on EF application to the olive oil sector are 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, oil mills and waste management could be, highlighting the phase that requires more biologically productive area in terms of the 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 the size of the deficit. It is likely that the reuse of part of the wastes as fertilisers may reduce the overshoot and decrease the farm dependence on additional external goods. The main strength of the EF methodology is its ability to explain, 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, the EF could be an effective and immediate tool to communicate how much the agricultural and transformation practices in the olive oil sector exceed the ecological limits and how to manage and use the available resources in a sustainable way.

The olive oil sector is also assessed using methodologies other than 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. the eco-centric viewpoint), which LCA does not take into account (e.g. human labour). 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 scarce. Recently, Neri et al. (2012) compared organic and conventional production in Italy using emergy evaluation. This study highlights that both systems present higher values related to the agricultural phase, even though the organic farm shows a higher environmental performance for all the phases. The conventional system uses 4 % renewable resources, while the organic system uses 12 %. Human labour represents 4.33 % and 25.10 % of the total emergy flow for conventional and organic systems, respectively. This study is the only one to show the importance of human labour, which 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 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 dry land (i.e. non-irrigated) regardless of their style of management and, on the other hand, the greater non-renewable energy efficiency of organic olive growing in comparison with conventional production. The use of '*alperujo*' (olive wet husk) compost and temporary plant covers and the reduction of machinery use to when it is strictly necessary are proposed as possible improvements.

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

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

An Environmental Product Declaration (EPD) is a verified document containing the quantification of the environmental performance of a product or service according to the appropriate categories of parameters calculated using the LCA methodology (ISO 2006a). 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 the environmental performance 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 (Environdec 2014). The requirements for EPDs of a certain product category are defined in Product Category Rules (PCRs). PCRs are sets of rules, requirements and guidelines for developing an EPD for one or more product categories that can fulfill equivalent functions. PCRs ensure that similar procedures are used when creating EPDs, allowing the comparison between different EPDs.

As far as food products are concerned, numerous PCRs have been developed, including the one for the product category 'virgin olive oil and its fractions' made according to the definition provided on the International Olive Council website (Environdec 2014) and according to Regs. EC 1019/2002, EC 796/2002 and subsequent amendments. On the contrary, 'lampante' virgin olive oil and olive pomace olive oil are excluded. This PCR expired on 31st December 2013; the updated document has been published in April 2014. On the basis of what is reported in the reference PCR, when developing the EPD, the functional unit of 1 L of virgin olive oil must be declared as a unit of the product including the packaging; information on the end-of-life phase of the packaging is also necessary.

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 the 'processing' of raw materials, the extraction of virgin olive oil from the olive fruits, waste management, storage of olive oil and primary packaging (including transportation) 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 by the customer or consumer and 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. In addition, all the data reported in the EPD are subjected to independent verification of the declaration and data, according to the ISO standard 14025:2006 (ISO 2006a). Furthermore, the declaration has to be updated every year 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 in the EPD increased. At the 30th September 2013, 8 EPDs were registered, 7 of which refer to Italian olive oil industries or associations. In particular, the first experience involved 68 Greek olive growers from the Peloponnese and Crete, organised by 3 farmers' organisations: Nileas, Pezea Union and Mirabello Union. This experience was soon followed, in the Italian context, by the EPDs achieved by the firm APOLIO (Cappelletti et al. 2012) and afterwards by the association ASSOPROLI Bari and by the firms De Cecco and Monini; the latter certified 4 different types of extra virgin olive oil: 'Granfruttato', 'Classico', 'Poggiolo' and 'Delicato'.

Through a deep analysis of the data referring to the environmental performances reported in the eight EPDs, some differences can be highlighted. These are due not only to the variety of the systems analysed (olive grove management, olive oil extraction system, packaging and transportation), but also to the different assumptions made when the system boundaries were defined. In relation to this issue, indeed, even though there are some differences in the inventory data, all the EPDs include the agricultural phase (upstream phases). Regarding the downstream phases, not all the EPDs consider the use phase and the end of life of the packaging material.

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

These different assumptions contribute to increasing the variability of the total results (as highlighted in Table 2.4). Starting from the upstream phase, it should be pointed out that a comparison among the different types of olive cultivation cannot be made due to the lack of detailed information. Sure enough, the EPDs give information about the olive grove management system, but there are no quantitative and qualitative data as far as the agricultural practices are concerned: these details could be very useful, especially regarding the business relations with large-scale retailers.

Table 2.4 Environmental performance referred to the olive oil EPDs. (Source: www.environdec.com)

Impact catgory	Unit	F.G.N. P.U. and M.U. 2012.	Apolio 2012	Assoproli 2012	De Cecco 2012	Monini Gran-fruttato 2012c	Monini Classico 2012a	Monini Poggiolo 2012d	Monini Delicato 2012b	Min	Max	Average	St. Dev.
Non ren. 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 ren. energy	MJ	18.6	8.1	40.6	17.3	59	47.5	45.7	53.3	8.1	59	36.3	18.9
Renew-able 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	57,582
Renew-able 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

Table 2.4 (continued)

Impact catgory	Unit	F.G.N. P.U. and M.U. 2012.	Apolio 2012	Assoproli 2012	De Cecco 2012	Monini Gran-fruttato 2012c	Monini Classico 2012a	Monini Poggiolo 2012d	Monini Delicato 2012b	Min	Max	Average	St. Dev.
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	$m^2 \times yr$	9.723	23.064	23.391	2.055	0.058	0.060	0.061	0.060	0.058	23.391	7.309	10.354

As regards the analysis of the core phase, the information about the olive oil extraction processes is not always complete. The processes are often described in a generic way and unclear aspects are presented in the related environmental performance.

By analysing the packaging phase, the choice of the container is a further aspect that 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 0.5 L in some cases (ASSOPROLI Bari), in other cases 0.75 L (the group Nileas, Pezea Union and Mirabello Union) and in others again 1 L (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, by considering the same functional unit, the biggest container being advantaged (fewer kilograms of glass per litre of extra virgin olive oil) (Cappelletti et al. 2007).

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

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

By comparing the aggregated data referring to the environmental performance among the EPDs registered for the olive oil, significant variability in the results is highlighted. In all the cases, the results underline the high environmental impact of the agricultural phases: for almost all the impact categories analysed, indeed, over 50 % of the total impact derives from the olive cultivation phase. This is an aspect that is frequently observed when an LCA study is carried out in the olive oil sector (Salomone et al. 2010b); 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. 2013a) and decide on the best practices to be applied to the whole sector.

2.3.6 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 due to uncertainty, which often affects the results of the analysis (Avraamides and Fatta 2008).

Olive oil is one of the most representative products of the food sector in the Mediterranean area, and related environmental LCA studies show significant environmental impacts associated with the resource 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 the agricultural processes, such as the crop variety, and the different levels of mechanisation in the 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 in selecting the option, among several, that attains the best environmental performance, according to a set of criteria defined by the decision maker (Beccali et al. 2002a, b).

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) assessed different scenarios concerning the agricultural phase, the olive transport from the grove to the mill and the extraction phase. The application of MCA identified five optimal scenarios, according to the evaluation criteria defined by the following rules: (1) five environmental criteria, preferring scenarios characterised by a low level of field mechanisation, a short transport distance and highly efficient extraction plants exploiting reused energy from field and plant wastes (pruning and pomace stone); and (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 for the economic criteria, due to the mechanised field management and a significant olive yield, and a medium score for 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 groves containing an olive mill. Then, LCA was 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 results of the MCA: the traditional grove scenario involves 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's energy requirement. Conversely, the worst eco-profile was found in the high-intensity scenario, in which by-products (pomace and vegetation water) are treated as waste.

In other studies, multi-criteria analyses have been conducted for the interpretation of LCA results. Among these, in Cavallaro and Salomone (2010), the joint use of LCA and a multi-criteria algorithm was developed and applied to the olive oil chain. The tool derives from PROMETHEE (Preference Ranking Organization Method on Enrichment Evaluation) (Brans and Vincke 1985), using the outranking approach based on a pair-wise comparison of alternatives for each criterion. Such a tool was applied to eight scenarios of conventional and organic olive oil production and assessed following a life cycle approach. The results show that the preferable scenario is 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 avoided production of fertiliser 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 the other involving considerable use of pesticides and chemical fertilisers.

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

2.4 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 Sect. 2.3, it emerged that, as of 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 presented hereafter focuses only on the applicative case studies that used the LCA methodology connected directly or indirectly with the olive oil production supply chain, so that papers reporting literature reviews, methodological discussions, application in the table olive sector and the application of LCT tools other than LCA were excluded (resulting in the inclusion of 50 scientific articles in the following analysis).
2. Data collection concerning the applicative and methodological aspects related to the identified case studies—after the mapping, all the data relevant to the comparative analysis were collected for each study by using a dual input channel information flow:
   - a checklist, following the ISO 14044:2006 requirement structure (ISO 2006c), 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 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 to this specific sector of analysis (it is necessary to clarify, however, that 24 % of the questionnaires were not considered 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 the 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 depth of analysis; they report the results, more or less exhaustive, of applicative case studies carried out on the cultivation of olives, olive oil extraction, olive oil packaging and/or treatment of waste in the olive oil industry. As far as the form of publication and the methodology used are concerned, 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 Sect. 2.3, 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 in conjunction with other assessment methods—such as life cycle costing or another 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's 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.

2.4.1 The 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 (ISO 2006c), because the choice of the functional unit, the identification of the system boundaries, the time horizon of the study and, in more general terms, the depth and direction of the whole study will depend on its delineation. As shown in Fig. 2.2, most of the papers surveyed have as their scope the evaluation of the potential environmental impacts (60 %), the identification of the environmental burdens (58 %), the identification of hot spots (35 %)

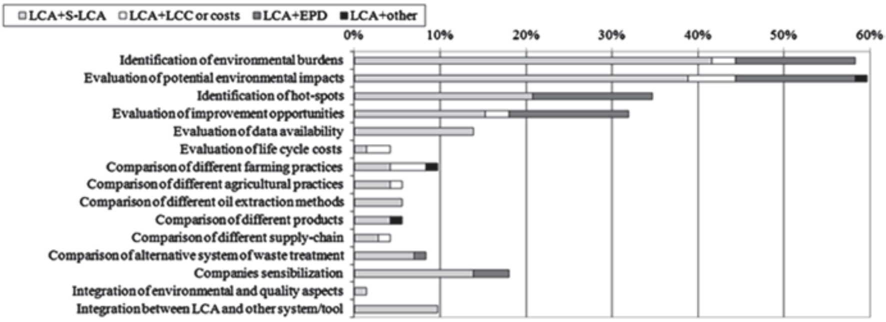

Fig. 2.2 The goal and scope in the surveyed case studies

and the evaluation of improvement opportunities (32 %) (each study may have more than one goal). Furthermore, the various kinds of comparative evaluation (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, none clearly define the intended audience, except EPDs, which obviously are disclosed to the public.

2.4.2 *The Functional Unit*

Figure 2.3 shows the functional unit (FU) adopted in the case studies surveyed. The FU should be consistent with the goal and scope of the study—ISO 14044:2006, 4.2.3.2 (ISO 2006c). 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 in a few cases, for example the one

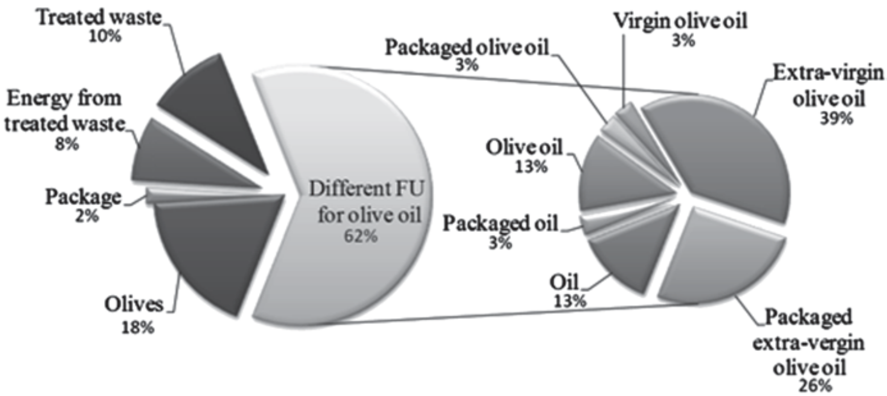

Fig. 2.3 The functional unit (FU) in the surveyed case studies

including a specific reference to the quality characteristic of the product (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 in a blend of refined oils and virgin oils (excluding the lampante virgin oil) (see Sect. 2.2).

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. However, 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 us to highlight that 24 % of the responding authors declared that they had encountered difficulties in choosing the FU, mainly linked to the comparison of completely different olive oils. Indeed, 50 % of the analysed papers report comparative studies mainly focusing on the comparison of cultivation practices and of the different olive oil extraction methods (see Fig. 2.4). Exploring the answers of the authors participating in the investigation, further information can be outlined; for example, it can be observed that 36 % of the authors of comparative studies declared themselves to have faced problems in the definition of the goal and scope requirement, while only 16 % of the authors of non-comparative studies encountered problems in this phase of the LCA study. Examining the comparative studies in more detail, the main problems in goal and scope definition were mainly linked to the choice of a proper FU (78 %): the chosen solution was often simplification and the functional unit selected was 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 the identification of 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 the FU were generally selected when the analysis was limited to the cultivation phase or when the whole production chain, including olive

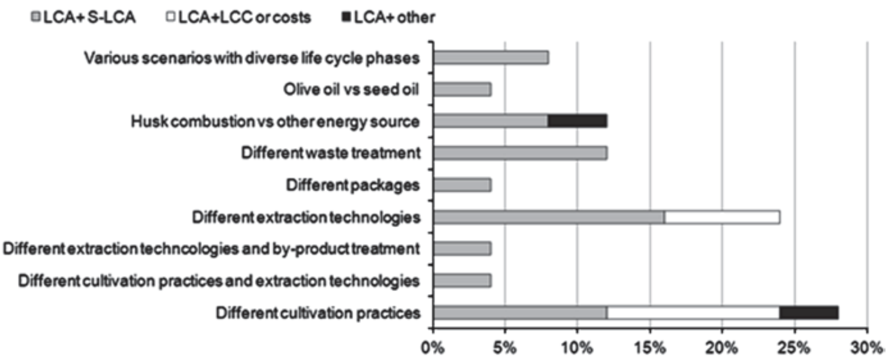

Fig. 2.4 The object of investigation in comparative case studies

oil waste treatment, was included. The choice of the functional unit, however, was strongly related to the purpose of the study and to the system boundaries.

2.4.3 The 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 the system boundaries, were determined by the lack of significant data about some processes of the chain (e.g. the 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 caused these processes to be excluded from the system boundaries. In other cases, doubts regarding 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. the quantity of olives processed).

Despite these differences, however, it was possible to verify, as shown in Fig. 2.5, 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 the other types of treatment of olive oil mill by-products/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 must be clearly stated and the reasons and implications for their omission must be explained—ISO 14044:2006, 4.2.3.3 (ISO 2006c). Of the analysed studies, 74 % specified the exclusion of some processes from the system boundaries, mainly

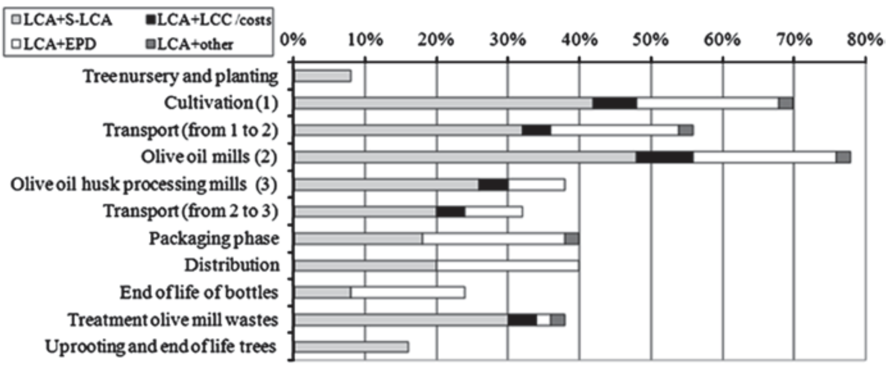

Fig. 2.5 The system boundaries in the surveyed case studies

because, being comparative studies, the processes were common to the systems analysed (24 %), while in the other cases, the reasons were mainly linked to missing data and/or incomplete information (24 %), but rarely were the implications clearly stated.

Even if the system boundaries and exclusions were not clearly detailed in all the studies, the analysis revealed that 70 % of the studies included in the analysis the cultivation phase, which was organic cultivation in only one case, 11 % of the cases integrated cultivation and 31 % included conventional cultivation, while 29 % of the 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 stated that this phase was excluded, mainly due to missing data (43 %), the consideration of the cultivation of olive trees more than 25 years old (36 %) or the comparative nature of the studies (14 %).

Concerning the olive oil extraction phase, the analysis revealed that 46 % of the studies that included this phase analysed the three-phase continuous system (including three cases of the de-stoning process), 8 % the two-phase continuous system, 8 % the discontinuous system and 5 % continuous centrifugation with a two-and-a-half-phase system (also called the modified system or water-saving system); 23 % investigated a comparison of different olive oil extraction methods, while the remainder did not specify the technology used (therefore failing to comply with the data quality requirements—see Sect. 2.4.4).

Focusing on the 76 % of case studies including olive oil mill by-product/waste treatment, 50 % included the treatment of olive oil husk in olive oil husk mills, while the remainder referred to other treatments of olive oil wet husk and olive oil wastewater. In particular, only 8 % of the studies 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.

2.4.4 Availability and Quality of Data

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

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

A total of 94 % of the analysed papers used primary data collected from various companies of the olive oil sector, 86 % used an LCA database and 21 % used data available in the literature. The most commonly used databases were Ecoinvent (54 %), the SimaPro Database (30 %), Buwal 250 (21 %), ETH-ESU 96 and IVAM LCA 3 (both cited in 16 % of the studies) and the PE International Database (9 %). In 40 % of the studies, the data quality was verified with various methods of analysis, 80 % using sensitivity analysis.

Concerning the 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), as well as problems related to emissions estimates of nitrogen and phosphate compounds and the 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 in databases about the production of pesticides; 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 commented on the lack of data on fertiliser production in the databases and their solution was always to use data from the 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 the databases and the lack of data regarding the emissions from herbicides; their solution was always to exclude them from the system boundaries;
- 53 % of the authors of these studies referred to the lack of data regarding emissions due to pesticide use and the difficulty in calculating the pesticide dispersion in soil, air and water; the solution was to use models to estimate emissions in 25 % of the studies (such as the successive enhancement of the model; Birkved and Hauschild 2006; Dijkman et al. 2012; Hauschild 2000), in 50 % of the cases the emissions were estimated using literature data 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 fertiliser use and the difficulty in calculating the dispersion in soil, air and water; the solution in 31 % of the cases was to use estimation models, such as the Brentrup model (Brentrup et al. 2000) for nitrogen compounds and data from the literature regarding the behaviour of phosphorus and potassium fertilisers; in 62 % of the cases the substances contained in the fertiliser were calculated using estimations from the literature (e.g. using the ratio between the real weight and the molecular weight and then estimating the emissions to the air, water and soil);
- 37 % of the authors had problems calculating the 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 the balance of CO_2 emissions and the lack of characterisation methods. The balance of CO_2 emissions was difficult to determine for 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 the literature or exclusion.

2.4.5 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 alternatives seem applicable, a sensitivity analysis should be conducted—ISO 14044:2006, 4.3.4 (ISO 2006c). Among the applied studies, 36 % used some form of allocation: of these analyses, 56 % used allocation methods for olive oil and for olive oil husk; 17 % for 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 also applied allocation to husk and wastewater or to 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 and in 28 % of cases by price and mass; the remainder did not mention the allocation method.

Allocation, especially in systems in which 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 to how to allocate the environmental load of the olive oil extraction process (among olive oil and the other by-products), but also difficulties in the representation of the reuse of pruning residues as natural fertilisers. The most commonly cited solutions were the expansion of the 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.

2.4.6 Life Cycle Impact Assessment (LCIA)

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

Regarding the impact assessment, only 12 % of the studies reported all the 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 the papers lacked sufficient elements to be able to detect the full data. Focusing only on the papers in which the information was specified, the most frequently 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) or the addition of the land use, the energy content or weight factors that take economic aspects into account. On the contrary, the changes to the method Eco-Indicator 99 (particularly the E/E) mainly described the costs and benefits of olive oil for 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 %).

2.4.7 Interpretation and Tools Supporting the Interpretation Analysis

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

All the reviewed studies report information on the interpretation phase, though with different levels of depth. In all of these, it was possible to identify the significant issues, but papers reporting conclusions, recommendations and limitations are scarce. 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 enable unequivocal conclusions to be reached. However, it can certainly be outlined that 51 % of the studies that accounted for both the agricultural and the other stages of the life cycle (with or without the intermediate stage of transport) identified the agricultural phase as the most polluting. In 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 polluting substances were fertilisers, pesticides and energy consumption.

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

2.4.8 Critical Review

A critical review (CR) by 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 (ISO 2006c). Except for EPDs, none of the other examined studies present elements suggesting that a critical review was carried out by external independent experts. Even though a CR undoubtedly improves the credibility of a study, it is still rarely practised, maybe due to the additional costs incurred, and only organisations working with environmental labelling or product declarations push themselves to demonstrate the quality of their LCA results with a CR. The International Organisation for Standardisation recently published (May 2014) a technical specification based on the critical review process in order to specify better the requirements contained in the ISO 14044 (ISO 2014a).

2.5 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 the LCT approaches applied in the olive industry (presented in Sect. 2.3) and the critical comparative analysis of the applicative LCA case studies in the olive oil production supply chain (presented in Sect. 2.4) allowed a better understanding of the specific methodological and applicative issues that a practitioner might encounter when applying the LCA methodology in the sector of olive oil production, and many points for reflection and improvement emerged.

When performing an LCA study, the first preliminary suggestion is to gain 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 the related technical reports and technical specifications;
- 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 the carbon footprint of products ISO/TS 14067: 2013 (ISO 2013a) and the forthcoming standard on water footprint (ISO 2014b);
- the Ecological Footprint Standard (Ecological Footprint Standard, 2009).
- Furthermore, some guidelines specifically focus on food products, such as:
- the 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 the stages from raw material acquisition through processing, distribution, use, end-of-life processes and all the relevant related environmental impacts.

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

2.5.1 The 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 its aims, methods of impact assessment and intended application. Furthermore, the scope should include the definition of the functional unit and 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 the goal and scope delineation will affect the choice of the functional unit, the identification of the system boundaries, the time horizon of the study and, in more general terms, the depth and direction of the whole study, caution should be applied when defining them; in particular, some elements that deserve to be highlighted are:

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

2.5.2 The Functional Unit

Choosing the functional unit (FU) is one of the very first critical tasks encountered when 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 as 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 Sect. 2.4.2, 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 the 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; however, due to the extremely wide variability in the quality of the oils (the price of an extra virgin olive oil rises from a few euros per litre to a few tens of euros per litre), it is very important also to include the product quality in the functional unit. But how can the quality of 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 and the E vitamin and tocopherol content. Hence, how can the most appropriate FU be identified? Indeed, different authors of LCAs in this specific productive sector have encountered difficulties in choosing the 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, though, some guidelines could be suggested, as summarised in the following sub-paragraphs and in Table 2.5.

When the LCA aims to analyse 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 types of olive oil (extra virgin, virgin, etc.), and the packaging should be included, especially if the LCA results should be declared in an EPD (as indicated in the PCR 'virgin olive oil and its fractions' of the International EPD System®).

When the LCA focuses on one or two specific phases of the life cycle of olive oil production, the FU should be chosen in order to provide better 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 lies in choosing an FU that 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 quantitative ways: for instance, due to the much stronger taste of the extra virgin olive oil than the seed oil (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 that carry out the same function, which will be, for example, one unit of extra virgin olive oil versus four units of sunflower oil.

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

Requirement	Possible choices	Recommended when
Functional unit	Hectare	The system boundaries include only the cultivation process
	Olives	The 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	The system boundaries include only waste treatment processes

In comparative analysis among extra virgin olive oils (the best quality of olive oils), indicators of the olive oil quality should be taken into consideration, as the prices or, if available, the score that the olive oil has received in the panel test (EC 1991).

When the nutritional characteristics of the product are at the core of the goal and scope of the study, the quantity of antioxidants (polyphenols and tocopherols) present per litre/kg of extra virgin olive oil could be considered. A functional unit of this kind allows researchers to consider not only the yields per hectare (which greatly affect the environmental impact attributable to the FU as oil, olive oil and extra virgin olive oil), but also the quality of the product, which is sometimes overlooked in industrial production. Another suggestion to follow is to use a set of different functional units (quantity or volume, price, 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. Therefore, the choice of an appropriate FU for an LCA study in the olive oil sector seems to be an issue requiring particular attention; in Table 2.5, some suggestions are highlighted.

2.5.3 The System Boundaries

The choice of the processes that should be included in or excluded from the study depends on the defined goal and scope, 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, the system boundaries are clearly indicated in the PCR 'virgin olive oil and its fractions' of the International EPD System®, which specifies the requirements for the definition of system boundaries (divided into 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 the relevant life cycle stages and processes; they should be defined following general supply chain logic, including all the stages: agricultural, industrial, by-product 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. Concerning the carbon balance, one should try to avoid it equalling zero, but 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 the total carbon balance is negative (thus good for the environment).

The literature review and the critical comparative analysis presented in the previous paragraphs highlight that, regarding the definition of the system boundaries, the main problems encountered by the authors of the surveyed studies were determined by the lack of significant data on some specific processes of the chain, which caused these processes to be excluded from the system boundaries, which in turn caused the need to redefine and recalibrate the goal and scope of the study (according to the iterative nature of LCA methodology). This means that one of the most significant issues on which further research work should be focused is the availability of LCI data, especially for some kinds of processes for which there is still a lack of complete and reliable data, as considered more extensively in Sect. 2.5.4.

2.5.4 Quality of Data

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

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

- The production of some specific kinds of fertilisers, herbicides and pesticides—this problem is usually tackled by 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 approached by excluding these emissions or estimating them using a specific model of dispersion, such as the Brentrup model for fertiliser dispersion, and the successive enhancements of the PestLCI model (Birkved and Hauschild 2006; Dijkman et al. 2012; Hauschild 2000) for pesticide dispersion. In general, the direct emissions from chemicals should be stressed more in environmental assessments of the cultivation phase, but a few times they have been included in the calculation. It is also important to underline that a more complete database on chemicals should lead to a more 'realistic' evaluation of the potential impacts;
- The balance of CO_2 emissions—this calculation is generally omitted (thus implicitly considering the carbon balance as net zero); 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 characterisation methods, generic data collected from commercial and free databases or estimations from the literature were used (Carvalho et al. 2012; Iraldo et al. 2013; Nardino et al. 2013; Palese et al. 2013; Sofo et al. 2005); it should also be highlighted that the CO_2 absorbed by the plants during their vegetative cycle (the age of plants plays 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;
- The use of pruning residues as natural fertilisers—frequently the destination of pruning residues should also be included, because they are often used as fertiliser or for domestic heating, bringing significant benefits for certain impact categories;
- Plant breeding and tree planting—few studies include the establishment of olive groves, generally because they consider new cultivation with young trees; furthermore, the PCR 'virgin olive oil and its fractions' of the International EPD System® specifies the inclusion of this process only 'if the olive grove life time is expected to be less than 25 years', but, even if the PCR does not mention it, in this case the end-life of the olive groves should also be considered;
- Double counting and incorrect attributions—when collecting primary data in an agricultural firm that produces mainly olives/olive oil (with or without a private mill), generally data related to different processes (mechanical processing of the soil, phytosanitary treatments, canopy management, fertilisation, etc.) will be available and will often be detailed and precise; however, if the company has many cultivars, special care should be paid to reporting all the data obtained for 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 industrial processes involved are lacking, so that emissions are only related to energy consumption) and above all in the waste treatment phase (which is still lacking relevant data for many processes that characterise the olive oil production supply chain). Examples of processes characterised by a general lack of data are: the combustion of olive pomace and pits; the quality characteristics of pomace compost and the different types of pomace; emissions from composting activities; emissions from the combustion of exhausted pomace; emissions from the spreading of OMW on soil, etc. In particular, OMW is a significant potential pollutant (high phytotoxicity, see Roig et al. 2006), but also contains 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, the choice of the FU becomes critical and it must made 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 datum to the functional unit must be undertaken with extreme caution. The variety of cultivars and the variety of all the management operations of the olive grove are the variables that need to be taken into account when 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 the phase of oil extraction. The variability of the oil and water content, the kneading time frames 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 these 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 have probably already been discussed by the scientific community, the issues related to the waste treatment of this sector (primarily for pomace and wastewater) are more specific to this area and inevitably more attention is necessary for this aspect.

Generally, little attention is paid to the transport phase. The EU produces over 70 % of the world's olive oil, and the most important countries that import the product are the USA, Brazil and Japan. In this respect, the following question arises: is it best to produce the most environmentally effective olive oils with low impact and transport them for thousands of kilometres or is it best to produce olive oils with conventional impacts and consume them 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 that is generally not considered in LCA studies for reasons of lacking data is human labour, which in the olive oil production sector is a fundamental input. It plays a primary role, especially concerning traditional and organic systems, in the soil and the management, pruning and harvesting phases. In this direction, it could be important to integrate other methodologies (e.g. emergy evaluation) with the LCA in order to obtain a more complete and coherent view of the unsustainability of systems. For example, the combination of macroeconomic analysis and LCA may prove to be particularly useful since, compared with detailed life cycle inventories, many models of entire economies employ a much smaller number of categories to represent 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 through other methodologies, different from LCA, as well. For example, the EF could be an effective and immediate tool to communicate how much agricultural and transformation practices in the olive oil sector exceed the ecological limits and how to manage and use the available resources in a sustainable way.

In general terms, the use of literature data can be suggested for the background system and plant/field-specific data for the foreground. High-quality data are the basis of any high-quality product environmental assessment. 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 that are compliant with the ILCD Data Network entry-level requirements (EC 2012). Secondary data should be country-specific. To assess the data quality, the PEF data quality indicator (EC 2013b) should be used. The data and calculations need to be transparent, enabling external peer reviews to be undertaken. Estimations are very frequently not accurate; therefore, if possible, they should be avoided, even if this could cause the exclusion of phases from the system boundaries. In addition, assumptions made due to a lack of data should be clearly declared because they often cause high variability and incomparability among different case studies.

Moreover, the results should be presented in as disaggregated a form as possible to facilitate comparisons and to understand better 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 for 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 the LCA findings for decision making or comparative assertions.

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

2.5.5 Allocation Methods

Following the ISO requirements—ISO 14044:2006, 4.3.4 (ISO 2006c), 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 olive oil production, the most common solutions cited by authors are 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 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 whether allocation based on the underlying of physical relationships is appropriate, economic allocation should be performed as a sensitivity analysis.

However, the allocation procedures in the olive oil sector should take into account the fact that the systems of this sector are characterised by one main product (olive oil) of generally high quality and thus high value as well as a large quantity of low-value by-products (pomace, OMW) that can be used as fuel and/or for composting purposes, which means that allocation 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 the mass and the economic value is needed in order to balance the quantities of by-products obtained with their low economic value).

2.5.6 Life Cycle Impact Assessment (LCIA)

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

Furthermore, 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, alternatively, after the grouping and weighting phase, the contribution of each impact category. The absolute values are useful in order to quantify the results for each impact category in a simply and understandable way.

In an 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; the emission of substances to water contributing to oxygen depletion; and emission linked to 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's 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, particularly in the agricultural step, the water use indicator should 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 measure the environmental problems they are intended to represent consistently. This is, for example, the case of land use, for which it is actually not possible to perform a complete assessment of all the connected impacts (essentially due to the lack of data); land use is currently assessed using a few key impacts and for a complete assessment further research is necessary to deal with the unresolved problems.

In addition, water use impact assessment, of more recent interest in LCA with respect to land use, needs improvements in environmental assessment schemes. Water use has been increasingly considered important since climate change and different assessment methods have begun to be developed, but improved inventory data and agreement on which LCIA methods should be used for the assessment of relevant aspects are necessary.

In general, it can be observed that the 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.

2.5.7 Interpretation

By following the ISO standards, the 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 previously mentioned, partly specific to this production and partly in 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 kinds 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 treatments;

- allocation methods;
- some impact methods (such as land use and water use);
- and all the other data of an uncertain source or of an estimated nature.

2.5.8 Critical Review

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

The analysis performed put in evidence the issue that the CR of experts is still rarely practised (maybe due to the additional costs incurred), and only organisations working with environmental labelling 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 practised for each LCA study, on one hand to reduce the variability and subjectivity and on the other hand to increase the credibility (e.g. ISO/TS 14071:2014).

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

Conclusions

The critical comparative analysis allows some general hot spots of the olive and olive oil supply chain to be highlighted:

- When comparing different kinds of vegetable oil, olive oil resulted as more eco-compatible than sunflower seed oil for all the categories except for land use, and for both systems the phase with the greatest impact 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 one with the greatest impact in almost all the impact categories (Avraamides and Fatta 2008; Christodoulopoulou et al. 2011; Iraldo et al. 2013; Salomone 2002; Testa et al. 2012);
- When focusing on the cultivation phase, the environmental impacts are mainly due to the use of fertilisers that cause eutrophication and acidification (Nicoletti and Notarnicola 2000; Salomone 2002), as well as the use of pesticides and land use in conventional olive cultivation (Olivieri et al. 2005b, 2007a). Considering different practices, it can be observed that the irrigation system is more eco-compatible than the dry system thanks to its higher olive productivity (Nicoletti and Notarnicola 2000) and conventional scenarios highlight higher environmental loads than organic ones (except for the impact categories associated with land use) (Olivieri et al. 2005a, b; Salomone and Ioppolo 2012; Salomone et al. 2010a);

- When focusing on the olive oil extraction phase (even if the agricultural stage is more significant than the processing one) 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 as 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 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 examples were analysed in the studies, e.g. olive mill waste water recovery as fertiliser (Testa et al. 2012), energetic exploitation of pomace stone (Cini et al. 2008) and the recovery of olive pits used as fuel (Russo et al. 2008), the 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 for reflection. The processes identified as those with a 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 can a more efficient and environmentally friendly local olive oil production chain be designed and how can LCA be used 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, the lessons learned allow us to highlight that in this sector research is needed to increase the credibility of the existing LCA data and the priority is the improvement and expansion of databases for these substances; however, the models that estimate their dispersion in water, air and soil must also be simplified. Despite these limitations, this study can help us to understand better 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 the current knowledge concerning where future research and developments should be concentrated. However, the olive oil chain should not be interpreted as simple olive processing and olive oil production, followed by the problem of disposal and waste management. The whole olive oil chain must include the systems, treatment plants and waste recovery to obtain biomass for energy use, to produce compost and other substances that are useful to the cosmetic and pharmaceutical industries. Thus, this sector is multi-product and each option must be properly assessed considering the whole chain from both environmental and economic points of view, and LCA should be used as a starting point for the continuous improvement procedure with regard to the environment, identifying the inputs, processes or phases with the most significant potential impacts and considering measures for their control.

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