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Analysis and trends for Life Cycle Assessment of olive oil production

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Analysis and trends for Life Cycle Assessment of olive oil production

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ABSTRACT

For over 10 years, the olive oil sector has been largely studied through Life Cycle Assessment (LCA). Thus, a review of the numerous results and the different evaluated scenarios is relevant for future LCA studies on this important agro-economic sector of the Mediterranean region.

The herein present work, based on scientific and technical literature aims to compare system boundaries, functional units, life cycle inventories, allocation, impact assessments, and interpretations from the currently existing LCAs of olive oil. Furthermore, an analysis of the assessment of biogenic carbon has been carried out among the reviewed papers.

As a result, 23 relevant LCA studies on olive oil production or olives cultivation (for olive oil production) were identified. Analysis of the literature converged on an unequivocal environmental hotspot, the agricultural phase; which represents the most impactful phase of the olive oil life cycle, due in particular to fertilisation, pesticides treatment, and irrigation. Waste management and distribution also appear to represent a crucial issue. The comparison work made on climate change impact assessment is on the order of magnitude of 460 kg CO₂-eq/ton of olive and 1.6 kg CO₂-eq/L of olive oil. This study highlights the complexity of carrying out an LCA on the olive oil sector. At last, best practices and methodological recommendations were matured.

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1. Introduction

Given its organoleptic properties, olive oil consumption trends have been increasing worldwide. Consumption went from 2.590×10^6 tons (t) in the 2000/2001 crop year (a period from 1 October to 30 September) to 2.726×10^6 t in 2016/2017, an increase of 5.2% in the last seventeen years. Over the same time span, worldwide production has constantly risen (Fig. 1), despite continuous fluctuations from year to year, linked to the uncertainty of climate and alternate-year bearing. It is estimated for 2017/2018 a worldwide consumption of 3.008×10^6 t, a rise of 10.4% in only one year (IOC, 2018a). Performance figures for the 2017/2018 crop year point to a worldwide production growth by 29.4% compared to the last crop year. The International Olive Council (IOC) data for November 2018 estimate world production at 3.314×10^6 t (IOC, 2018b).

The European Union (EU) account for more than 93% of all the olive oil production in the world. Three-quarters of world production is concentrated in only three Mediterranean countries: Spain, Italy and Greece, each accounting of 41%, 18% and 12% respectively (IOC, 2018a).

The production of olive oil represents a strategic sector for EU countries as it faces emerging competition with the arrival of new producing countries outside the EU. The major competitors include Argentina, Australia, Mexico, Chile, New Zealand, South Africa and the United States of America (Salomone and Ioppolo, 2012). These new producers use intensive and highly mechanised methods that increase yields and reduce operational costs. Concerning the consumption in the EU, this has been decreasing over the years (Fig. 1), no one at the IOC has been capable to explain these trends.

Despite the economic importance of this food product in the mentioned Mediterranean countries, olive oil production is associated with several negative effects on the environment which causes depletion of resources, land degradation, air emissions and waste generation (Salomone et al., 2015).

Moreover, the olive oil production sector faces crucial issues concerning waste management. Eighty percent of the olives mass is composed of olive pulp and stones. Thus, the extraction process yields 4 times more waste than oil. The composition of the waste products depends on extraction technologies; which include press, 2-phase or 3-phase systems (Cinar and Alma, 2008).

Additionally, in olive oil-producing countries (typically Mediterranean), climate is sunny, warm and dry; the overexploitation of the relatively thin and fragile organic soil layer might lead to soil erosion. This problem is exacerbated by irrigation, the use of pesticides and mineral fertilisers. Also, it can be attributed to waste management, as a large proportion of organic waste from olive mills are applied directly on the same soils. According to Roig et al. (2006) the negative effects are associated to its high mineral salt content, on the other hand, the carbon content and soil fertility might be improved with this organic matter application thanks to its high nutrient concentration (like potassium).

Given that, the Mediterranean region is subject to particular levels of dryness, water is scarce and represents an issue of significant importance. In such areas, irrigation remains a sensitive topic that is environmental and socially controversial. Environmental assessments carried out for water-consuming systems in said arid regions need to take into account irrigation processes.

The impacts can differ considerably due to the variability in cultivation practices (tree planting, fertilisation, irrigation, pest

treatment, pruning and harvesting) extraction technologies used in the olive oil production, waste management (by-products) and packaging end of life (landfill, incineration, recycling). The olive oil sector, like any other economic sector, must now ensure its sustainability. In order to achieve this state, it is important to evaluate the arising problems throughout the life cycle of olive oil.

2. Description of LCA studies on olive oil sector

In this context, LCA has been applied to olive oil for more than ten years in order to identify environmental hotspots and to propose recommendations to limit environmental impacts. An Italian review was published in the 2010 conference proceedings of the “7th International Conference on Life Cycle Assessment in the Agri-Food Sector” (Salomone et al., 2010) where a high number (i.e., 23) of studies on olive oil were identified, with the limitation of its exclusive focus on Italian olive oil production. Five years later, a book was published under the same name (Salomone et al., 2015), in which a wider and deeper analysis was carried out as it includes international case studies, life cycle thinking tools and “olive industry” case studies instead of only olive oil ones.

Banias et al. (2017) published a systematic literature review of scientific publications about the use of environmental tools in the life cycle of olive oil, taking into account the farming phase, manufacturing, packaging, warehousing, transportation and reverse logistics. Their analysis included 98 papers that were published until the end of 2015. Only 18 are LCA studies. The codification for their reviewed papers consisted of three parts: country of publication, the tools used to estimate the impact, and the serial number of the paper.

The present paper proposes an innovative review study about LCA of olive oil based on scientific and technical literature. This review has an added value compared to the existing ones given its emphasis on: (i) taking into account recent environmental LCA studies on olive oil and olives for olive oil; (ii) comparing system boundaries, functional units, life cycle inventories, allocation, impact assessments and interpretations; (iii) the topic inclusion of biogenic carbon on environmental balance of bioproducts; (iv) carrying out a comparison of results on climate change (kg CO₂-eq).

The present work has identified 23 relevant LCA studies of olive oil or of olives for the production of olive oil. Fig. 2 illustrates the citation interconnections found between these 23 studies and the two reviews mentioned above. We can notice (Fig. 2) that Avraamides and Fatta (2008) and Salomone and Ioppolo (2012) are the most cited studies for being one of the first, to the authors knowledge, in publishing a complete study on LCA on olive oil.

As the main function of the system is the production of olive oil, all articles dealing with the LCA of olive, olive oil and olive oil waste management were taken into account.

To select documents and studies, available online scientific and technical literature were searched. Articles were retrieved from the Web of Science, Scopus and Science Direct databases. Keywords used were “olive oil” plus “life cycle assessment”, “environmental assessment”, “environmental impact”, “climate change”, “carbon footprint”, “sustainability”, “life cycle costing”, “carbon sequestration” and “waste management”. The search was conducted on literature that was published up to December 2018.

A compendium of 23 relevant LCA studies of olive oil or of olives for the production of olive oil with detailed information is

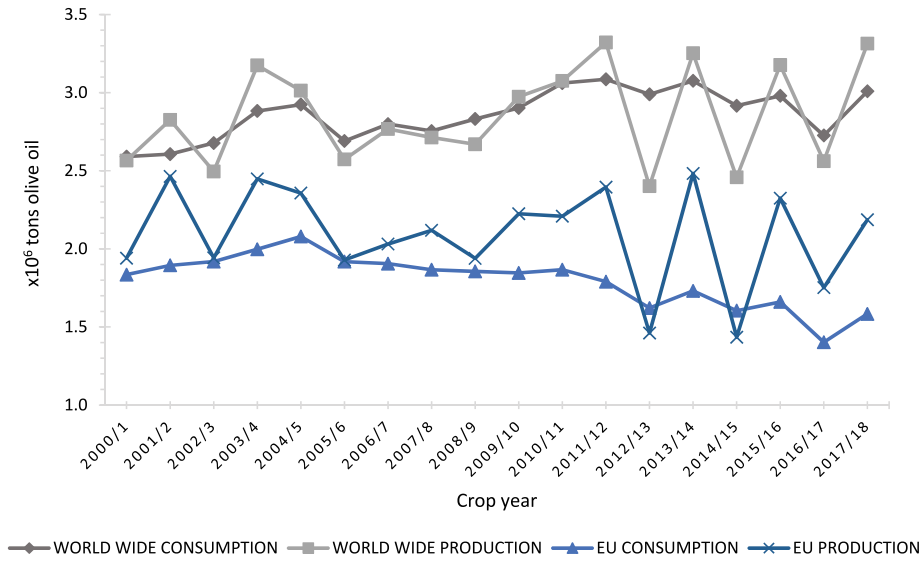
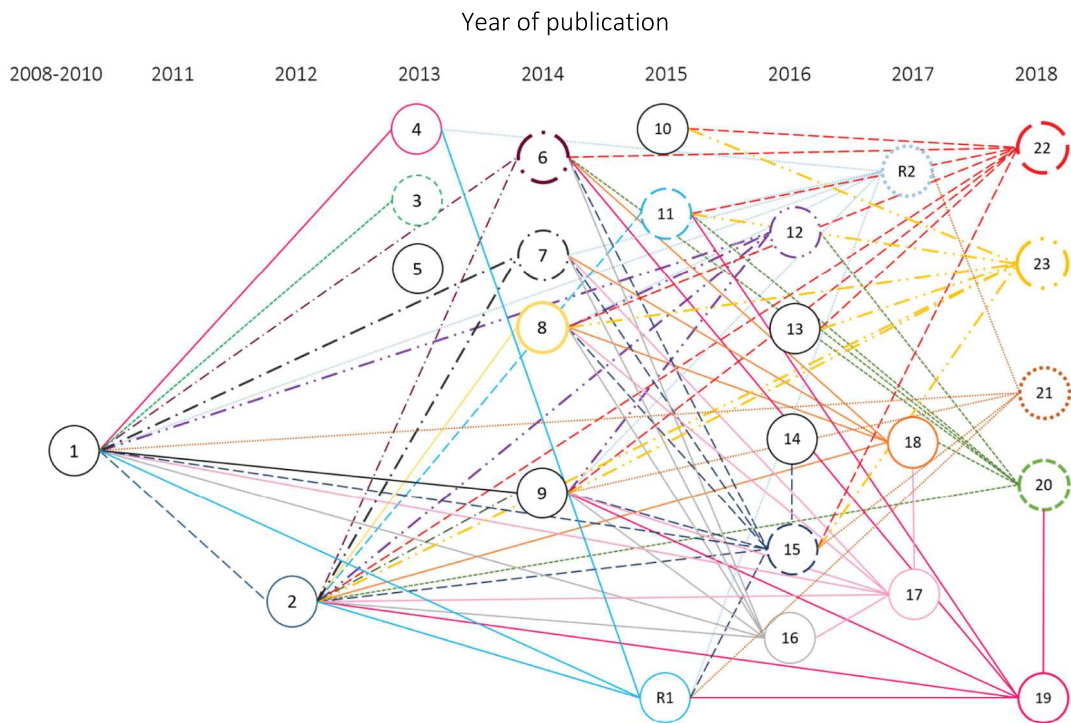


Fig. 1. Olive oil production vs consumption.



1 (Avraamides and Fatta, 2008), 2 (Salomone and Ioppolo, 2012), 3 (Accorsi et al., 2013), 4 (Chatzisyemon et al., 2013), 5 (Espi et al., 2013), 6 (Mohamad et al., 2014), 7 (Proietti et al., 2014), 8 (Rajaeifar et al., 2014), 9 (Rinaldi et al., 2014), 10 (El Hanandeh, 2015), 11 (Tsarouhas et al., 2015), 12 (El Hanandeh and Gharaibeh, 2016), 13 (Christoforou and Fokaides, 2016), 14 (Guiso et al., 2016), 15 (Pattara et al., 2016), 16 (Proietti et al., 2016), 17 (Proietti et al., 2017), 18 (Romero-Gómez et al., 2017), 19 (Bernardi et al., 2018), 20 (De Luca et al., 2018), 21 (Navarro et al., 2018), 22 (Parascanu et al., 2018a), 23 (Parascanu et al., 2018b), R1 (Salomone et al., 2015), R2 (Banias et al., 2017)

Fig. 2. Citation interconnections found between the 23 studies and the two reviews done on LCA of the olive oil sector.

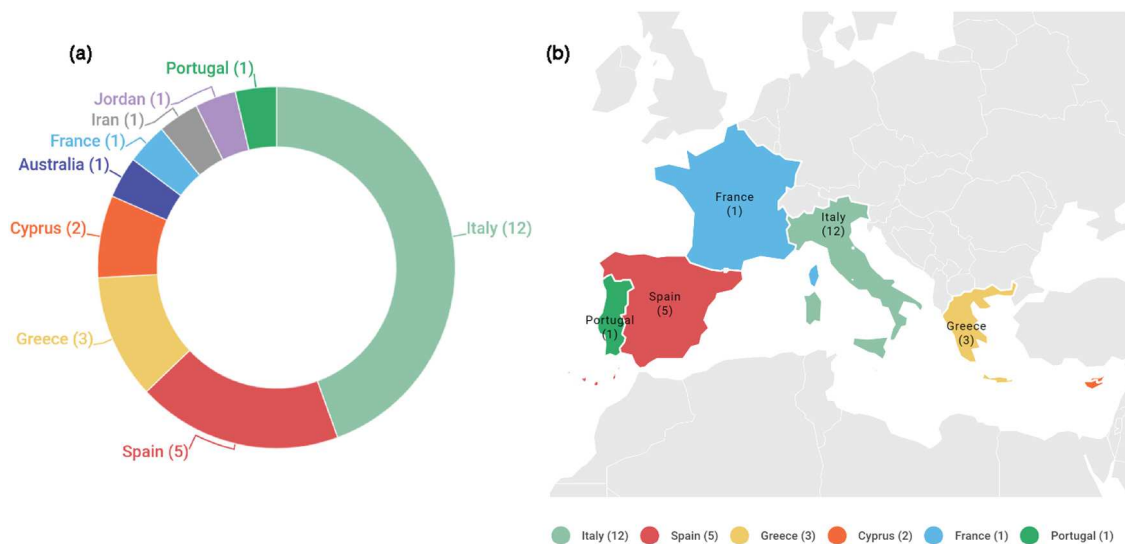


Fig. 3. Proportion and geographic dispersion of studies: (a) Worldwide, (b) Europe.

presented in Table 1. The information (Table 1) is presented in columns with the following headings:

- CODE. The numerical codes for the publications are the same on Fig. 2 and with along all the Tables presented on this study.
 - TITLE. The original title of the publication and its reference.
 - COUNTRY. The country where the study of the cultivation and production of olive oil was carried out. Not the country of origin or establishment of the authors.
 - KEYWORDS. Key terms and signal words of the publications (in italics those adapted by our study, in the absence of the originals).
 - DATA SOURCES. Origin of data of the publications used for its life cycle inventories.
 - SCOPE. System boundaries and topic of study: olives, olive oil or olive mill waste (in italics those adapted by our study, in the absence of the originals).
 - FU. Functional unit.
 - SOFTWARE. Computer tool used for the LCA studies.
 - ENVIRONMENTAL IMPACT CATEGORIES. Impact categories used on the environmental LCA studies.
- The acronyms used in Table 1 are explained below it.

2.1. LCA framework applied to olive oil

LCA of the olive oil production sector is based on ISO 14040 and ISO 14044 standards as a general framework (ISO, 2006a,b). More specifically, a Product Category Rules (PCR) for Environmental Product Declaration (EPD) document was created based on these ISO standards and which gives a more specific hypothesis for the olive oil sector (EPD, 2010). An EPD for Crete olive oil producers was created in 2012 (EPD, 2012a). An Italian olive oil company also created its EPD in 2012 (EPD, 2012b).

2.2. Key features

Studies have been conducted on three different types of documents: review papers, papers, and international scientific conference proceedings. Among the 25 relevant life cycle studies related to the olive oil sector, two are review papers (Banias et al., 2017; Salomone et al., 2015), 23 focus on environmental life cycle assessment, five on carbon sequestration (Pattara et al., 2016; Proietti et al., 2014, 2017, 2016; Rinaldi et al., 2014) and four focus on waste treatment (Chatzisyneon et al., 2013;

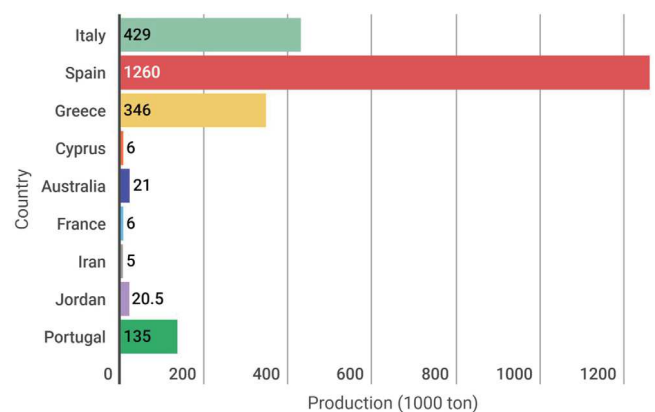


Fig. 4. Olive oil world production in 2017/2018.

Christoforou and Fokaides, 2016; Parascanu et al., 2018a,b). Among the 23 environmental LCA studies included in this review, only six were already included in the review made by Banias et al. (2017).

Only environmental LCA studies on olive oil and on olives for olive oil have been considered. The search was conducted on literature that was published since 2008 and up to December 2018. The study of olive oils and olive groves was carried out from Italy (12), Spain (5), Greece (3), Cyprus (2), Australia (1), Iran (1), Jordan (1), France (1) and Portugal (1). Fig. 3 illustrates the proportions of publications in different countries. Italy, Spain and Greece were the most active countries in regard to this topic, which coincides with their leadership on worldwide olive oil production. However, Italy is significantly more active than Spain, despite the fact that their production volume is between 2 and 3 times lower than the Spanish production (IOC, 2018b). Fig. 4 evidences the olive oil world production for the year 2017/2018, the IOC (2018a) defines the 'olive crop year' as the period from 1 October to 30 September.

2.3. International projects

Six European projects related to olive oil and based on the LCA methodology have been performed: ECOIL, INFOIL, oLIVECLIMA

Table 1

Main characteristics of the 23 relevant LCA studies of olive oil or of olives cultivation for olive oil production.

Code	Title	Country	Keywords	Data sources	Scope	FU	Software	Environmental impact categories
1	Resource consumption and emissions from olive oil production: a life cycle inventory case study in Cyprus (Avraamides and Fatta, 2008)	Cyprus	LCI, Olive oil, Resource, Emissions	Questionnaires, interviews, on-site measurements, inventory databases.	Cradle-to-gate (Olive oil)	1 L EVOO	SimaPro 7	GHG
2	Environmental impacts of olive oil production: a Life Cycle Assessment case study in the province of Messina (Sicily) (Salomone and Ioppolo, 2012)	Italy	LCA, Olive oil, EI, Scenarios analysis	Questionnaires, interviews. International literature, databases.	Cradle-to-gate (Olive oil)	1 ton of olives	SimaPro 7.2	CML v.2 2000
3	Life cycle assessment of an extra-virgin olive oil supply chain (Accorsi et al., 2013)	Italy	FSC, LCA, Food distribution, Food specialties, Sustainability	Questionnaires, interviews, on-site measurements, datasheets, technical reports, manuals Ecoinvent.	Cradle-to-grave (Olive oil)	1 L EVOO	SimaPro 7.1.8	GWP, OD, POF, AA, E, NREC
4	Life cycle assessment of advanced oxidation processes for olive mill wastewater treatment (Chatzisyneon et al., 2013)	Greece	LCA, Olive mill waste, Photocatalysis, Electrolysis, Wet air oxidation	Ecoinvent 2.2.	Gate-to-gate (OMW)	1 L Olive mill waste	SimaPro 7.3.3	-IPCC v1.02, 2007 -ReCiPe v1.06, 2008: GWP
5	Report on life cycle and cost analysis according to the requirements established by ISO 14040: Life cycle analysis. Principles and frame of reference (Espí et al., 2013)	France Spain Portugal	LCA, CF, OO	Questionnaires, Ecoinvent 2.2	Cradle-to-grave (Olive oil)	1 L EVOO/ VOO/ OO	SimaPro 7	IPCC v1.02, 2007. GWP100
6	Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment and Life Cycle Costing perspectives (Mohamad et al., 2014)	Italy	LCA, LCC, EI, Organic, Olive, Profitability	Questionnaires Literature review Ecoinvent.	Cradle-to-gate (Olives)	1 ha	SimaPro 7.1	Eco-indicator 99 (H); HH, EQ, RD
7	Carbon footprint of an olive tree grove (Proietti et al., 2014)	Italy	LCA, CF, Olea europaea, Carbon stock, CO2 sequestration	On site measurements, Ecoinvent.	Cradle-to-gate (Olives)	1 ha	SimaPro 7.1	-Eco-indicator 99: LU, MD, FD, CC -EPD, 2007: GWP
8	Energy-economic life cycle assessment (LCA) and greenhouse gas emissions analysis of olive oil production in Iran (Rajaeifar et al., 2014)	Iran	CobbeDouglass, Energy-economic analysis, GHG, LCA, Olive oil	Face-to-face questionnaires, Excel spreadsheets.	Cradle-to-gate (Olive oil)	1 ha	Microsoft Excel	GHG
9	Assessment of carbon footprint and energy performance of the extra virgin olive oil chain in Umbria, Italy (Rinaldi et al., 2014)	Italy	LCA, EVOO, GW, Cumulative energy demand	Questionnaires, on-site measurements, Ecoinvent.	Cradle-to-grave (Olive oil)	1 L EVOO	SimaPro 7.3	-IPCC, 2006: CF, EF

(continued on next page)

Table 1 (continued).

	Title	Country	Keywords	Data origin	Scope	FU	Software	Environmental impact categories
10	Energy recovery alternatives for the sustainable management of olive oil industry waste in Australia: life cycle assessment (El Hanandeh, 2015)	Australia	LCA, Energy from waste, WM, Olive husk, Renewable energy	Databases: ELCD, NREL, AusLCI	Manufacturing, transportation, processing of the olive waste	1 Mg of olive solid waste	OpenLCA	-ReCiPe Midpoint (H):f OD, GWP100, E, AA, HT, FD, IR, POF
11	Life Cycle Assessment of olive oil production in Greece (Tsarouhas et al., 2015)	Greece	LCA, Olive oil production, EI	Personal contact with growers, literature review.	Cradle-to-gate (Olive oil)	1 L EVOO	-	-Eco-indicator 99, GWP, AA, E, POF
12	Environmental efficiency of olive oil production by small and micro-scale farmers in northern Jordan: Life cycle assessment (El Hanandeh and Gharaibeh, 2016)	Jordan	LCA, Olive oil, EI Micro-scale farming, Uncertainty analysis	Survey of farm management practices.	Cradle-to-gate (Olive oil)	1 kg of olive oil	openLCA v1.4.1, Excel 2010 with Analysis ToolPak	- ReCiPe Midpoint (H): AA, PMF, HT, GWP100, LU
13	Life cycle assessment (LCA) of olive husk torrefaction (Christoforou and Fokaides, 2016)	Cyprus	LCA, Torrefaction, Biomass, Olive husk	GaBi database	Gate-to-gate (Olive mill waste)	1 ton of torrefied olive husk	GaBi	-CML, 2001: GWP100, AA, E, OD, AD
14	Environmental impact assessment of three packages for high-quality extra-virgin olive oil (Guiso et al., 2016)	Italy	LCA, GWP, Shelf life, GHG	Technical sheets, literature review, Ecoinvent 3.	Cradle-to-grave (Olive oil)	1 L of bottling capacity	SimaPro 8.0.2	- IPCC, 2013: GWP, OD, POF, AA, E, NREC
15	Carbon Footprint of extra olive oil: a comparative and driver analysis of different production processes in Centre Italy (Pattara et al., 2016)	Italy	CF, LCA, GHG, CC	Survey of farm management practices.	Cradle-to-gate (Olive oil)	5 L EVOO	SimaPro 8.0.1	- IPCC, 2007: GWP100
16	Assessment of carbon balance in intensive and extensive tree cultivation systems for oak, olive, poplar and walnut plantation (Proietti et al., 2016)	Italy	Tree cultivation systems, Carbon stock, LCA, CO2 sequestration	Datasheets, Ecoinvent.	Gate-to-gate (Olives)	1 ha	SimaPro 8.0.3.14	EPD,2013
17	Extra Virgin Olive oil as carbon negative product: Experimental analysis and validation of results (Proietti et al., 2017)	Italy	Carbon stock, GHG, CF, LCA, Olea europaea, Environmental sustainability	Face-to-face questionnaires, Interviews, technical datasheets.	Cradle-to-gate (Olive oil)	1 L EVOO	SimaPro 8	E, GWP100, POF, AA, CF

(continued on next page)

Table 1 (continued).

	Title	Country	Keywords	Data origin	Scope	FU	Software	Environmental impact categories
18	Optimization of olive growing practices in Spain from a life cycle assessment perspective (Romero-Gómez et al., 2017)	Spain	EI, Olive growing systems, Integrated farming, LCA	Experimental data, Ecoinvent.	Cradle-to-gate (Olives)	1 ton of olives	SimaPro 8.0.4.30	ILCD, 2011 V1.05/EU27 2010: CC, AA, FWE, FWET, LU, WRD
19	Harvesting system sustainability in Mediterranean olive cultivation (Bernardi et al., 2018)	Italy	Mechanical harvesting, Olive orchard, Work productivity, Economic sustainability, LCA, EI	Questionnaires, on-site measurements, Ecoinvent 3.3.	Gate-to-gate (Olives)	1 ha, 1 kg	SimaPro 8.1	ReCiPe -midpoint (H) -endpoint (H)
20	Evaluation of sustainable innovations in olive growing systems: A Life Cycle Sustainability Assessment case study in southern Italy (De Luca et al., 2018)	Italy	Agricultural innovations, Olive growing systems, LCSA, Multi criteria decision analysis	Specific in-field surveys with semi-structured questionnaires, Background processes: Ecoinvent 3.2.	Cradle-to-gate (Olives)	1 ha	SimaPro	- IPCC, 2013: CC - CML v3.03: HT, FWET, MET, TET - ReCiPe midpoint: LU
21	Tackling the Relevance of Packaging in Life Cycle Assessment of Virgin Olive Oil and the Environmental Consequences of Regulation (Navarro et al., 2018)	Spain	CF, Eco-design, Policy making, Glass, Tin and polyethylene terephthalate	Questionnaires, personal communication, GaBi professional 2015, Ecoinvent 3.0	Cradle-to-grave (Olive oil)	0.5 L bottle of VOO	GaBi	CML, 2001 (updated 2015)
22	Life cycle assessment of olive pomace valorisation through pyrolysis (Parascanu et al., 2018a)	Spain	LCA, Olive pomace, Pyrolysis, SimaPro	On site measurements, Ecoinvent.	Cradle-to-grave (Olive mill waste)	100 kg olive pomace	SimaPro 8.2	ReCiPe -midpoint (H) -endpoint (H)
23	Environmental assessment of olive pomace valorisation through two different thermochemical processes for energy production (Parascanu et al., 2018b)	Spain	LCA, Olive pomace, Gasification, Combustion	On site measurements, Ecoinvent 3.4.	Cradle-to-gate (Olive mill waste)	1MJ of energy production	SimaPro 8.2	ReCiPe -midpoint (H) -endpoint (H)

AA=acidification; AD=abiotic depletion; ALO=agricultural land occupation; CC=climate change; CF=carbon footprint; E=eutrophication; EI=environmental impact; EQ=ecosystem quality; EVOO=extra virgin olive oil; FD=fossil depletion : FSC=food supply chain; FU=functional unit; FWD=fresh water depletion; FWE=freshwater eutrophication; FWET=fresh water ecotoxicity; GHG=greenhouse gases; GWP=global warming potential; H=hierarchist; HH=human health; HT=human toxicity; IR=ionizing radiation; LCA=life cycle assessment; LCC=life cycle costing; LCI=life cycle inventory; LCSA=life cycle sustainability assessment; LU=land use; MD=minerals depletion; ME=marine eutrophication; MET=marine ecotoxicity; NLT=natural land transformation; NREC=non renewable energy consumption; OD=ozone depletion; PMF=particulate matter formation; POF=photochemical oxidant formation; RD=resource depletion; TA=terrestrial acidification; TET=terrestrial ecotoxicity; ULO=urban land occupation; WM=waste management; WRD=water resource depletion.

and OLIVE4CLIMATE (by the LIFE programme of the European commission); OLIVERO and OilCA.

The ECOIL project (LIFE04 ENV/GR/110) covered the full cycle of olive oil production in Spain, Cyprus and Greece (ECOIL, 2004). It generated 3 main reports (Avraamides and Fatta, 2006; Cortes, 2006; Georgiou et al., 2006) on LCA implementation and one scientific article, which was written on partial results of the project (Avraamides and Fatta, 2008).

The INFOIL project (LIFE08 INF/GR/581) focused on the promotion of sustainable olive oil production and consumption patterns in two major regions of Greece with very high olive oil production, Crete and Peloponnesus (INFOIL, 2010).

The oLIVECLIMA project (LIFE11 ENV/GR/942) focused on olive-producing areas in Greece. Its main aim was to introduce new cultivation practices for tree crops in order to find cost-effective means for mitigation and adaptation to climate change. Also, it was designed to boost the uptake of CO₂ by olive trees from the atmosphere and store it in soil as organic matter (oLIVECLIMA, 2012).

The OLIVE4CLIMATE (LIFE15 CCM/IT/141) project conducted an LCA with a holistic vision of the processes and products associated with the production of EVOO, along with a quantification of the carbon sequestration potential in the olive groves. This approach was tested in three Mediterranean countries with heterogeneous environmental conditions: Italy, Greece and Israel (OLIVE4CLIMATE, 2016). One research paper on carbon sequestration (Proietti et al., 2017) studied on the herein presented bibliographical study was partially funded by this project.

The OLIVERO project undertook physical and socio-economic research on Sloping and Mountainous Olive Production Systems (SMOPS) in five target areas in southern Europe (Portugal, Spain, Italy, and Greece). In these target areas 24 different SMOPS were distinguished, with their respective productive, ecological, economic and social functions, and were grouped into five major types: traditional, semi-intensive low input, semi-intensive high input, intensive and organic production systems (Graaff et al., 2010). The main aim of the OLIVERO project was to assess the future of SMOPS in the Mediterranean basin (Stroosnijder et al., 2008).

The OilCA project was funded by the Interreg IV B SUDOE communitarian initiative. Its aim was to improve the competitiveness of the olive sector in the south-western Europe region, which includes Spain, Portugal and the South of France, known as SUDOE space (OilCA, 2011). The OilCA methodology was based on life cycle assessment (LCA) and life cycle costing (LCC) to identify opportunities for the optimisation of olive oil production (Carvalho et al., 2012). One report of Espi et al. (2013) on the LCA of olive oil production and an international conference proceeding (Busset et al., 2015) resulted from the OilCA project. The OilCA project generated a computing tool for carbon foot printing and a guideline for eco-labelling (OilCA, 2013).

3. Goal and scope definition

Most analyses of the life cycle of olives or olive oil have been done with an environmental and attributional approach. Regarding the herein presented bibliographical study, only one LCA assessment related to olive oil was conducted in accordance with the consequential approach (Accorsi et al., 2015) and one following a Life Cycle Sustainability Assessment (LCSA) methodology (De Luca et al., 2018).

Although Accorsi et al. (2015) worked on the environmental impacts associated with the bottled extra virgin olive oil life cycle, it only followed a consequential approach on the end-of-life treatments of package waste. The environmental impact categories were quantified in accordance with an attributional approach.

De Luca et al. (2018) conceived LCSA as an integrative and holistic methodology that takes into account environmental, economic and social constraints. The object of the analysis was the study of olive orchard management in a specific region of Italy. Three scenarios were chosen: a control scenario, a low-dosage/no-tillage (LDNT) scenario, and a zero chemical weeding scenario. The functional unit (FU) was 1 ha of cultivated surface, and the system boundary consisted of the agricultural production “from cradle to farm gate”. The results showed that LDNT scenario was the best option for environmental and economic perspectives. It caused lower emissions in terms of greenhouse gases (GHG) and achieved the best performance compared to the others for all the examined indicators, causing less overall impact throughout its life cycle; nevertheless, from a social point of view, LDNT scenario was the best one only in terms of psychosocial risk factors. In addition, the results showed that the actors are strongly concerned with toxicity and the social health of workers.

In order to understand the scope (system boundaries) it is necessary to have a general idea of the olive oil life cycle. It includes an agricultural phase, a production phase (at the olive mill), a waste (water and pomace) management phase, the packaging of the olive oil, the product distribution, its consumption, and the packaging end of life. A simplified block diagram representing the life cycle of olive oil is represented in Fig. 5.

3.1. Functional unit (FU)

Depending on the objectives of each life cycle study, FU might vary at the discretion of the practitioner. According to De Luca et al. (2018) FU strongly depends on the objectives of the assessment, the addressees of the study, and the typology of the investigation. In the selected studies (Table 1), functional units are defined as a quantity of olive (ton or kg), as cultivated surface area (ha), as volume (L) or as energy content (MJ). When the functional unit is the production of a quantity of olives, the types of olive were unspecified. The olive oil is classified into different categories, depending on quality indicators based on the physical and chemical and organoleptic properties. Olive oil properties are directly related to its extraction method. Studied forms of olive oil were either extra-virgin, virgin, current virgin olive oil, refined, derived from pomace or unspecified. Confusion might occur, for instance, because choosing 1 L of virgin olive oil as the FU is not equivalent to choosing 1 L of olive oil (Salomone and Ioppolo, 2012).

It is important to define the FU in the right way as it significantly influences the way an LCA is performed, as well as its results and their interpretation, especially in comparative studies (Hauschild et al., 2018). The FU according to the PCR for olive oil of the International EPD System is 1 L of olive oil. However, given the high variability of agricultural activities, it is important to be aware of all of the services or functions that are provided by the studied system. Here, a FU can be referred to as 1 ha of olive orchard (Bernardi et al., 2018; De Luca et al., 2018; Mohamad et al., 2014; Proietti et al., 2016, 2014; Rajaeifar et al., 2014), as mass unit such 1 kg of harvested product (Bernardi et al., 2018) or 1 ton of olives (Romero-Gómez et al., 2017; Salomone and Ioppolo, 2012), since the main objective of agricultural systems is food production (Romero-Gómez et al., 2017). Furthermore, for life cycle assessment focused on the waste treatment of olive mills, mass units were used, such 1 ton of olive solid waste (El Hanandeh, 2015), 1 ton of olive husk (Christoforou and Fokaides, 2016) and 100 kg of olive pomace (Parascanu et al., 2018a).

According to Hauschild et al. (2018) a well-formulated FU should be capable to respond to the following questions: “what?”, “how much?”, “for how long”/how many times?”, “where?” and “how well?”; and also, highlights the three types of mistakes

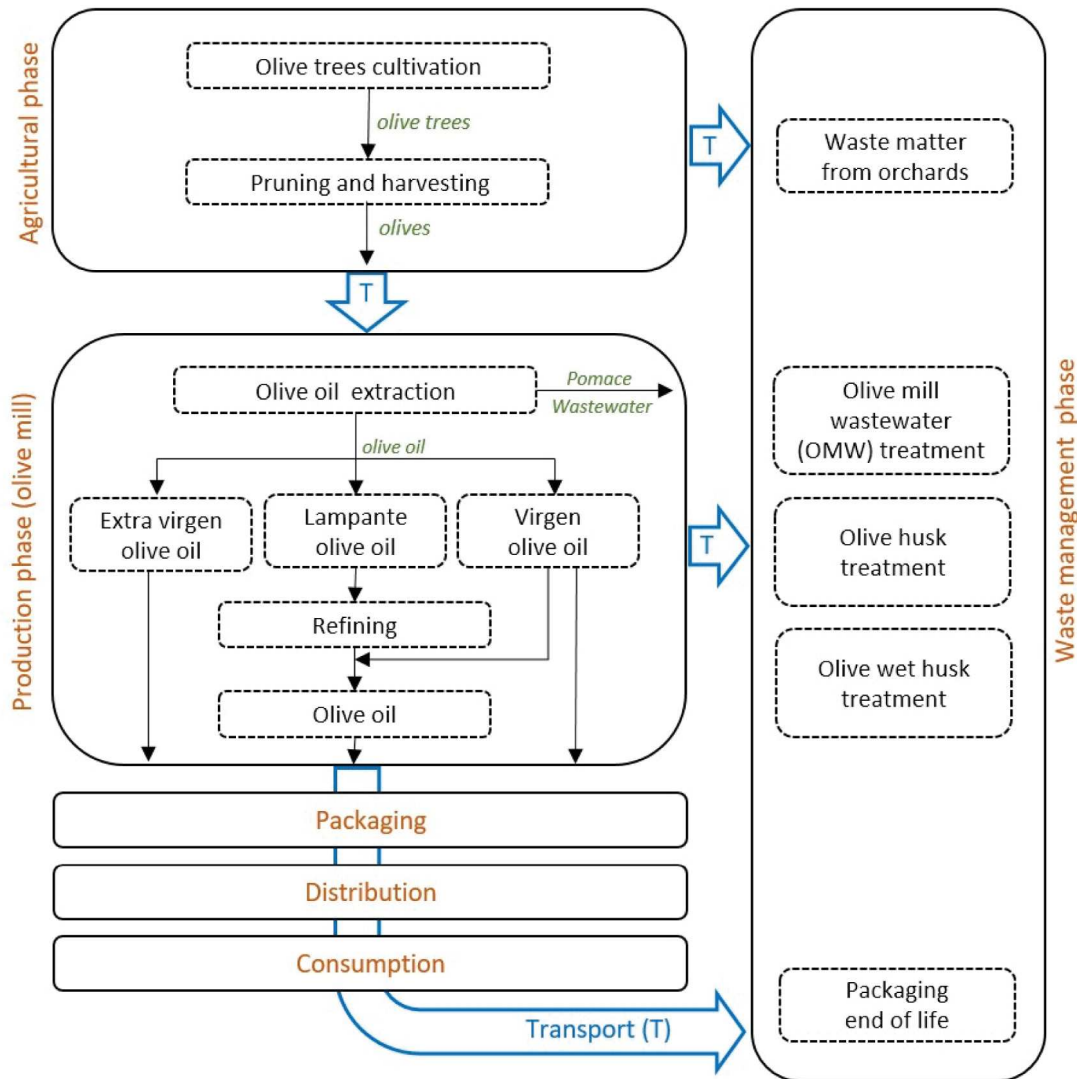


Fig. 5. The life cycle block diagram of olive oil.

when defining the FU: (1) Assuming that same physical quantity of product equals the same function, (2) Being overly restrictive, and (3) Using technical standards or legal requirements incorrectly. Any LCA study on olive oil answers correctly to these questions of FU and most of them made the first mistake.

3.2. Allocation

In numerous processes, more than one product is produced within the main product, called by-products/co-products. In such cases, it is necessary to "divide" the environmental impacts from the process between the products. Allocation and system expansion are the two methods to deal with the multi-functionality in LCA.

Allocation of environmental impacts between the product and co-products can be performed from an economic or physical point of view. As the allocation method can have a big influence on the study results, the identification of an appropriate allocation method is crucial. The ISO 14040-series recommend to use system expansion (disaggregate the given process into different subprocesses) whenever possible. In this paper, four articles were identified making allocation (Avraamides and Fatta, 2008; Parascanu et al., 2018b; Pattara et al., 2016; Rajaeifar et al., 2014) and three in which system expansion was used (El Hanandeh and Gharaibeh, 2016; Rinaldi et al., 2014; Salomone and

Ioppolo, 2012). Salomone and Ioppolo (2012) avoided allocation rules by extending system boundaries, including the production of all the by-products obtained in the olive oil industry. The same procedure was used by Rinaldi et al. (2014) and El Hanandeh and Gharaibeh (2016).

An example of physical allocation is found in an energy-economic LCA of the Iranian olive oil industry (Rajaeifar et al., 2014). They adopted a mass-based allocation method, commonly used to allocate by-products energy. This method allocates energy (deducted from the total energy input) to the mentioned by-product by its relative mass, in order to separate the energy used to produce the olive oil from the energy used to produce the olive pomace (Rajaeifar et al., 2014).

Examples of economic allocation can be found in LCA that made special attention in olive pomace, considering that olive oil has a higher unit price (Avraamides and Fatta, 2008; Parascanu et al., 2018b). The economic allocation is used for the olive pomace as a co-product, because it is intended to obtain its energy through a subsequent process and considered to reflect better the value of the products by granting most of the impacts to virgin olive oil (Parascanu et al., 2018b). Although pomace can be potentially used as fuel or for the production of pomace oil through further processing, it was traditionally treated as waste, thus considered of zero value (Avraamides and Fatta, 2008).

3.3. Biogenic carbon

Biogenic CO₂ emissions are defined as CO₂ emissions related to the natural carbon cycle, as well as those resulting from the combustion, harvest, digestion, fermentation, decomposition, or processing of biologically based materials (US EPA, 2018). Via photosynthesis, plants absorb CO₂ from the atmosphere and release O₂. A part of the absorbed CO₂ is returned to the atmosphere through respiration, while another portion is stored in various organic compounds, creating a so-called carbon sink (Proietti et al., 2016, 2014). Products and residues of the olive orchard cultivation contain biogenic carbon derived from the uptake of CO₂ by the crop (Rinaldi et al., 2014).

According to the *Vegetal-Based Chemistry Association* (2015), it is necessary to take into account the CO₂ stock in the plant because it allows a relevant comparison between fossil and bio-based products, between oils annual crops and perennial crops, and particularly, in “cradle-to-gate” but also in “cradle-to-grave” approach when the carbon is not entirely re-emitted (e.g. landfill) or in other forms than CO₂ (e.g. VOC emissions). They recommend disregarding the time lag of CO₂ emissions when calculating the environmental balance of bioproducts. The carbon sequestration is considered influential after ten years. If the life of the product is long, several standards recommend taking carbon sequestration into account, starting from a lifetime of the variable product according to the benchmarks (from 1 to 25 years).

In this review study, five papers mentioned the concept of biogenic carbon (Pattara et al., 2016; Proietti et al., 2014, 2016, 2017; Rinaldi et al., 2014) and three of them expressed having taken it into account (Proietti et al., 2014, 2016, 2017).

Rinaldi et al. (2014) explained that uptake and emissions of stored carbon were not explicitly reported because it was released within a year as a result of the oxidation of the carbon contained in the pruning wastes and in the olives along with the downstream life cycle stages. In addition, they did not take into account the trees' planting and end of life because the region has traditional cultivation with trees over 50 years old and its expected life exceeds 100 years.

Pattara et al. (2016) believe in a lack of uniformity in the application of the accounting methods of biogenic CO₂. In their LCA study, the carbon and related CO₂ were considered as belonging to the short carbon cycle and not in the general CO₂ budget.

Proietti et al. (2014) calculated the CO₂ sources and sinks in order to obtain the net carbon stock of the olive grove and its relation to the impact on climate change. The observations were made along the first 11 years from planting, which includes the crucial period of the life span of the olive grove. The results showed that the greatest impact occurred during the first year of olive grove cultivation with an annual average GWP100 value for the first 11 years of 1.507 t CO₂-eq/ha per year. Furthermore, considering the different years of cultivation, the greatest impact was made by the use of fertilisers and pesticides.

Proietti et al. (2016) contributed with an innovative environmental evaluation in terms of sequestered carbon. Olive trees showed an unexpected capacity to store CO₂-eq considering fruits and prunings in the calculation (28.916 kg CO₂ year⁻¹ plant⁻¹).

Proietti et al. (2017) calculated the carbon and CO₂ stock of the olive grove on a representative number of plants from their LCA study. They applied forest survey methodologies to estimate the biomass and the respective carbon stocked in olive tree permanent (trunk, branches, twigs and root collar, roots) and non-permanent components (prunings and fruits). The analysis showed that the tree non-permanent components give the major contribution in the amount of carbon stocked by olive trees. Their results are in accordance with Proietti et al. (2016).

According to ISO/TS 14067 (ISO/TS, 2018): “For all products, GHG emissions and removals are included as if released or removed at the beginning of the assessment period”. Calculations based on discounting or time-dependent characterisation factors are not part of the carbon footprint but may be reported separately in the study report.

On the other hand, the Publicly Available Specifications (PAS) 2050 builds on the existing ISO 14040 and 14044 standards (ISO, 2006a,b) and further clarify their implementation for the assessment of the GHG emissions of goods and services (BSI, 2011).

According to PAS 2050, both emissions (from biogenic and fossil sources) to the atmosphere and removals shall be accounted in an LCA. Human food and animal feed products are an exception if the biogenic carbon become part of the product. Regarding the case study of olive oil production, the biogenic carbon from the agricultural phase (olive tree permanent components, specially taking into account the longevity of olive groves) does not become part of the product (olive oil). Therefore, the assessment of biogenic carbon should be taken into account when performing an LCA that takes into account this phase within its system boundaries.

4. Impact assessment

4.1. Software

LCA results can be computed without LCA-specific software (e.g. Excel, MatLab) and that can be more educational and rigorous if done well. However, the computation of LCA usually becomes quite elaborated, so the use of specialised software is recommended. Impact assessment was performed with dedicated software in 20 of the 23 studies. The most popular was SimaPro (versions 7.0 to 8.2), chosen 17 times; especially in Italian studies. OpenLCA was used in Jordan and Australia (El Hanandeh, 2015; El Hanandeh and Gharaibeh, 2016). GaBi software appeared twice (Christoforou and Fokaides, 2016; Navarro et al., 2018). Lastly, Microsoft Excel was preferred by Rajaeifar et al. (2014). From the OiLCA project, a free software (OiLCATool) was specifically developed for olive oil producers to perform carbon footprinting and life cycle costing based on LCA methodology (OiLCA, 2013).

Moreover, coupling process modelling and LCA methodology has been considered, for example in chemical industry (Azapagic et al., 2006) and in agro-industry (Gillani et al., 2010). Parascanu et al. (2018a,b) coupled Aspen Plus[®] 8.8 with Simapro 8.2 in two studies of olive pomace valorisation. They used the Aspen Plus[®] 8.8 software to estimate the mass and the energy balances associated to the thermochemical process. The obtained data were subsequently introduced as inputs in the SimaPro 8.2 software for the environmental assessment.

4.2. Impact categories and methods

Life cycle impact assessment (LCIA) converts all inventoried flows into impacts on the environment indicators. In a LCIA, essentially two mainstream ways to derive characterisation factors are followed: mid-point and end-point indicators. The midpoint methods are applied to the characterisation factor to measure the impact, while the endpoint methods are applied to express the current damages.

In this review study, a large range of different evaluation methods was used for impact characterisation. Depending on the study period, the evaluation methods used were the most famous and recognised European methods: CML-IA, EPD, ReCiPe, IPCC and ILCD. Indeed, more than a third of the reviewed studies used

the ReCiPe method (Bernardi et al., 2018; Chatzisymeon et al., 2013; De Luca et al., 2018; El Hanandeh, 2015; El Hanandeh and Gharaibeh, 2016; Parascanu et al., 2018a,b). This method is a fusion of two methodologies, it takes the midpoint indicators from CML methodology and the endpoints indicators from Eco-indicator 99. The 18 impact categories at the mid-point method are: ozone depletion (OD), human toxicity (HT), ionizing radiation (IR), photochemical oxidant formation (POF), particulate matter formation (PMF), terrestrial acidification (TA), climate change (CC), terrestrial ecotoxicity (TET), agricultural land occupation (ALO), urban land occupation (ULO), natural land transformation (NLT), marine ecotoxicity (MET), marine eutrophication (ME), freshwater eutrophication (FWE), fresh water ecotoxicity (FWET), fossil depletion (FD), minerals depletion (MD), and fresh water depletion (FWD). The end-point method (ReCiPe end-point) allows to calculate the following impacts: damage to human health (HH), damage to ecosystem diversity (ED) and damage to resource availability (RA) (Huijbregts et al., 2016).

The second preferred method was IPCC single issue method (version 2006, 2007, 2013) (Chatzisymeon et al., 2013; De Luca et al., 2018; Espi et al., 2013; Guiso et al., 2016; Pattara et al., 2016; Rinaldi et al., 2014).

Global warming/climate change is the main evaluated midpoint impact category and is expressed as kg CO₂-eq. However, the other impact categories differ among the studies, thus, making comparisons between them might be difficult. It is important to remember that LCA is a “Multi-criteria” analysis that assesses multiple environmental impacts. Differently, carbon footprint is basically a “Mono-criteria” analysis as it focuses on only one environmental impact, climate change by GHG emission. In this review, three papers with mono-criteria analysis (GHG) were found (Avraamides and Fatta, 2008; Espi et al., 2013; Rajaeifar et al., 2014), which indicates a methodological simplification when called LCA.

5. Results and interpretations

5.1. Variability and complex comparison

All of the articles have been compared in terms of general characteristics, including methodology, functional unit, system limits, scenarios and different parameters taken into account depending on the study. These comparisons have highlighted the significant variability between the studies. Such variability resulted in difficulties in interpreting and comparing the results. Exhaustive lists of inventory results were missing in many of the studies. Functional units and certain units of similar flows (i.e., the quantity of diesel might be expressed in MJ, kWh, kg or L) were different. Differences in conversion factors might have contributed to increase error in calculation. Another source of divergence is the source of the indirect data. The use of different inventory databases, such as Ecoinvent, GaBi or ELCD, which are based on different methodologies, hypotheses and system boundaries, might have compromised feasible comparison. Furthermore, environmental impact comparison is a big challenge for the following two main reasons: (i) impact indicators are different and based on different hypotheses and (ii) the impact assessment step relies the inventory data.

5.2. Climate change category

Even if LCA is a multi-criteria analysis (as explained in point 4.2), the impact category preferred by many authors for their publications on LCA is the climate change category.

Two groups for comparison of results were possible. In the climate change impact category, two FU were comparable. Table 2 shows the studies with results on kg CO₂-eq/ton of olive

and Table 3 the studies on kg CO₂-eq/L of olive oil. In order to achieve this, the publications data have been reworked: the column named “climate change” with four sub-columns shows the unit, minimum and maximum data and the size of the sample, where applicable. The last column named “Climate change*” (with an asterisk) exhibits our converted average of the original data on publications with the interest of having comparable results. Table 2 makes it possible to compare results among four publications (coded 2, 8, 18 and 20). The scope of all of them is from cradle to gate, specifically for the agricultural phase. It is noticeable that they respect the same order of magnitude, with three of them around 425–489 kg CO₂-eq/ton. The result on publication coded 18 (Romero-Gómez et al., 2017) is 224 kg CO₂-eq/ton, this difference could be explained because 33% of its data came from intensive and super-intensive Spanish agricultural systems, so its yield could be higher than the others. Publication coded 8 (Rajaeifar et al., 2014) is the only one that made mass allocation: 20% of the total energy consumption from agricultural olive production, olive transportation, and oil extraction stages was allocated to the olive oil, the other 80% was allocated to the olive pomace. All the impacts from transportation to the customer centres were allocated to the olive oil because it is the only product transported in that stage (Rajaeifar et al., 2014). This work on mass allocation explains why it has the lowest result of Table 2.

On the other hand, Table 3 shows the results on kg CO₂-eq/L among five publications (coded 5, 9, 12, 15 and 17). The first two have a scope from cradle to grave but their results are not in the same order of magnitude. This is explainable because the second one took into account freezing and export by truck, ship and plane to USA, Japan, Germany and France from Italy, being the transportation by plane to USA (~9100 km) a big impact on the results (Rinaldi et al., 2014), while the first one took into account transports only by truck at regional, national and European level (~1300 km) (Espi et al., 2013). The last three publications have a scope from cradle to gate, and they respect the same order of magnitude, around 0.6–1.6 kg CO₂-eq/L. Even if the publication coded 15 (Pattara et al., 2016) and 17 (Proietti et al., 2017) have a different number of samples to calculate the average, they both converged at 1.6 kg CO₂-eq/L.

5.3. Hotspots in the olive oil life cycle

All of the studies with minimum cradle-to-mill-gate boundaries (agricultural phase + extraction phase) showed that the impacts of the agriculture phase were the most important (Avraamides and Fatta, 2008; Espi et al., 2013; Pattara et al., 2016; Tsarouhas et al., 2015). This conclusion is consistent with both previous reviews (Baniyas et al., 2017; Salomone et al., 2015). The cause for the predominance of agricultural phase is the fertilisation, the irrigation, and the phytosanitary treatment. Pruning also generates a large quantity of wood materials, which are generally burnt directly in the orchards without heat recovery or any type of valorisation. The agricultural phase is very complex and impacts numerous linked parameters. It is difficult to identify the influence of certain specific aspects of this phase due to the large range of possible scenarios.

Although distribution represents an important phase, it is only considered in 5 studies (Accorsi et al., 2013; Espi et al., 2013; Guiso et al., 2016; Navarro et al., 2018; Rinaldi et al., 2014). Distribution phase scenarios remain extremely variable because bottles can be directly purchased at the mill or distributed by truck, car, van, boat, train or plane. For these reasons, distribution is often excluded from studies. For similar reasons, the bottling phase (including bottle production and transport to bottling facilities) is rarely considered.

Table 2
Comparison of results on climate change (kg CO₂-eq/ton of olive).

Code	FU	Scope	Climate change (kg CO ₂ -eq/FU)			Conversion factor	Climate change *kg CO ₂ -eq/ton
			Unit	Min	Max		
2	1 ton of olives	Cradle-to-gate	kg CO ₂ -eq/ton	(n=4)	467	510	489
8	1 ha	Cradle-to-gate	1333 kg CO ₂ -eq/ha mass-alloc: 525 CO ₂ -eq/ha		-	-	425 168
18	1 ton of olives	Cradle-to-gate	kg CO ₂ -eq/ton	(n=12)	95.4	309	224
20	1 ha	Cradle-to-gate	CO ₂ -eq / ha 50yr	(n=3)	3.6 × 10 ⁵	3.8 × 10 ⁵	478

Table 3
Comparison of results on climate change (kg CO₂-eq/L).

Code	FU	Scope	Climate change (kg CO ₂ -eq/FU)			Conversion factor	Climate change *kg CO ₂ -eq/L
			Average	Min	Max		
5	1 L EVOO/ VOO/ OO	Cradle-to-grave	kg CO ₂ -eq/L	(n=3)	2.19	3.47	3
9	1 L EVOO	Cradle-to-grave	17.53 CO ₂ -eq/L				17.5
12	1 kg of OO	Cradle-to-gate	0.57 kg CO ₂ -eq/kg				0.6
15	5 L EVOO	Cradle-to-gate	kg CO ₂ eq/ 5L	(n=4)	4.48	10.10	1.6 (0,9 to 2)
17	1 L EVOO	Cradle-to-gate	kg CO ₂ eq/L	(n=7)	0.67	4.48	1.6

Also, the waste treatment is an important hotspot on the olive oil cycle. The impacts are highly variable from one study to another and might be considered as “avoided” impacts due to energy or nutrient recovery (Salomone and Ioppolo, 2012).

5.4. Extraction technologies

Comparison of extraction technologies appears to be the less variable step of all stages on the olive oil production. This notion can be explained by the following two main aspects: (i) the production of “virgin olive oil” is feasible using two types of systems (discontinuous and continuous), which limits the difference of the extraction chain; (ii) The extraction phase remains a low-impact phase, compared to the agricultural phase which is the most impactful phase. With these aspects, it is not significant to make an improvement that would lead to environmental benefits in the cradle-to-grave scope. Indirect technical consequences due to the type and quality of effluent represent a second relevant difference between extraction techniques (Cinar and Alma, 2008). The main way to reduce the environmental impacts at this stage would be choosing the system that produces waste that is easier to treat, namely, the 2-phase or 2.5-phase system (2-phase modified system). The studies which compared extraction technologies, came to the same conclusion as follows: the 3-phase system is the worst system, followed by the press. The 2-phase or 2.5-phase systems are the best systems (Salomone and Ioppolo, 2012). Oil quality, in terms of nutrients, might differ as a result of the different extraction techniques used. However, this aspect is not included into the LCA methodology, even if the quality of the product remains a key feature for decision-making in agro-industrial systems.

5.5. Packaging

Olive oil can be obtained nowadays in various presentations and it is very important to take it into account in the inventory analysis. Guiso et al. (2016) provided a comparative impact assessment for tin-plated cans, dimmed glass bottles and stainless steel bottles of EVOO. They outlined that packaging impact

decreases for larger sizes. Navarro et al. (2018) studied the contribution of glass polyethylene terephthalate (PET), and tin packages within the whole virgin olive oil life cycle.

On the study made by Espi et al. (2013), the most frequent container was PET (69.41%), followed by glass (24.12%) and tin (5.29%). They demonstrated that although the impact per gramme of smaller material corresponds to glass, the effect of the weight of the container per litre of packed oil made it the container with the greatest impact.

Packaging has an important contribution on finished product environmental impact, and that impact comes not only for the needs of extraction of raw materials and subsequent processing for the manufacture of the container but also, for the transport. This includes the transport of packages to the facilities where the oil is packaged and later, its commercial distribution. The impacts are greater when the transport is made by plane. Reducing the weight of the glass bottle could make a great contribution to reduce environmental impacts.

5.6. Waste management techniques

Waste is divided into the following 4 categories: (i) pruning residues, which are generally burnt (with or without heat recovery); (ii) pomace residues from 2-phase or press systems, which are sent for pomace olive oil extraction or directly burnt or spread into fields or composting; (iii) ashes resulting from incineration processes, which are spread; and (iv), wastewater from 3 phase systems, which is generally dried, spread or filtered. It remains a very complex issue of the sector because it represents a large quantity of organic matter (OilCA, 2011). In our studies of olive oil production LCA, four focus on waste treatment (Chatzisyneon et al., 2013; Christoforou and Fokaidis, 2016; Parascanu et al., 2018a,b) and they propose different approaches. Composting is the most impactful option because of the tractor usage for turning the waste matter; Oil husk extraction has lower impacts due to the use as fuels of exhausted pomace and stones (Salomone and Ioppolo, 2012).

5.7. Best practices and methodological recommendations

In terms of methodological perspectives, data quality improvement and uncertainty analysis remain crucial. Local data are also

needed because absolute results are strongly dependent on the studied zones (Espi et al., 2013). Reduction of the data uncertainty induced by the lack of real data and the use of literature models particularly for composting or olive wet pomace emissions appears crucial (Salomone and Ioppolo, 2012). Data quality remains a key issue. Local data and models are needed because climatic conditions are highly variable. Research is needed for improving impact factors, models of fertilisers and of pesticides dispersion; impact category models, such as land use, water use, loss of biodiversity and soil function impairment. From the analysis of the literature on LCA, it appears that the positive effects of soil management warrant further study. The impact on soil is the most difficult issue because of the variety, temporality and local properties of soil.

The most important practices concern the agricultural phase and treatments of wastes. Overall, organic cultivation is a way to reduce environmental impacts (EPD, 2012a). The recommended agricultural and waste treatments practices are: optimisation of soil management techniques, such as cover cropping and the incorporation of organic material in soil (i.e., residues from pruning (chopped but not burnt), weed, leaves and residues from olive oil extraction process) (EPD, 2012a,b). Reduction of the use of mineral fertilisers and pesticides (take into account the fate of pesticides in the fields). The inclusion of positive contribution of reduced fertiliser and energy use should be studied. The improvement of waste management impacts soil and groundwater when it is spread (Avraamides and Fatta, 2008). Also, the reduction of the use of diesel and replace it by biofuel obtained thanks to residues (Romero-Gómez et al., 2017; Tsarouhas et al., 2015). The use of renewable energies (Romero-Gómez et al., 2017) or energy obtained from residues (Christoforou and Fokaidis, 2016).

Additionally, it is important to include the quality aspect of the product (i.e., EVOO, VOO, OO) since it directly affects the functional unit and the used extraction techniques used. Considering the results, perspectives and recommendations offered by the studies, sensitive environmental hotspots, as well as limits, now appear well characterised. Nevertheless, any study includes all of the fields required by the ISO 14040 standard. Framework for communicating information about environmental footprints is available as a Product Category Rule, revealing a certain maturity of the topic and the application of LCA to olive oil production. Most notably, the agricultural practices and waste management approaches (strongly linked to agriculture phase) evolve important effects in terms of environmental impact assessment. Efforts should be focused on these issues that represent opportunities for reducing environmental impacts. In future studies, the choice of the FU should be unified and it must respect the rules of a well-defined FU (quantity + quality + duration), and they should have a well-defined goal and scope, along with avoiding allocation.

The inclusion of social aspects has been suggested by De Luca et al. (2018), and they addressed this issue combined with environmental LCA and life cycle costing in order to develop a complete "Life cycle sustainability assessment" (LCSA).

Despite the uniformity of the methodology used to calculate the biogenic carbon in the olive groves, it is very important to continue with these studies in order to take into account the sequestration of carbon in the plant and apply it to the calculation of its life cycle for the production of olive oil.

Finally, it is important to realise a multi-indicator study because the core reason for taking a life cycle perspective is that it allows identifying and preventing the burden shifting between life cycle stages and between environmental indicators.

6. Conclusions

In the light of this literature review, crucial environmental issues concerning the life cycle of olive oil and olive cultivation for the olive oil production have been extensively assessed and studied. In general, the goal and scope of the studies were focused on hotspot identification to enhance our knowledge on the life cycle of the system and on the comparison of different alternative systems. The critical analysis was conducted on 23 publications and two review papers between 2008 and 2018, including articles based on six European projects. Italy, Spain, and Greece were the most active publishing countries, which coincides with their leadership on worldwide olive oil production. Only one study concerned Life Cycle Sustainability Assessment. All the articles have been compared in terms of their general characteristics, methodology, functional unit, system limits, scenarios and further parameters taken into account depending on the study. For the goal and scope definition: functional units might vary at the discretion of the practitioner; allocation and system expansion are used to deal with the multifunctionality in LCA; five papers mentioned the concept of biogenic carbon. The assessment of biogenic carbon should be taken into account when performing an LCA with agricultural phase within its system boundaries. Even though LCA is a multicriteria analysis, climate change was the impact category preferred by many authors; with results on the order of magnitude of 460 kg CO₂-eq/ton of olive and 1.6 kg CO₂-eq/L of olive oil. The environmental hotspots were mainly the agriculture, waste treatment and distribution phase. Comparison of extraction technologies appeared to be the less variable step of all stages on the olive oil production. Packaging impact decreases for larger sizes of bottles. Some studies focused on waste treatment: composting is the most impactful option and the reuse of pomace and stones permits to reduce impacts on oil husk extraction.

Overall, the best practices, and methodological recommendations done were:

- Data quality improvement and uncertainty analysis is crucial;
- Local data and models are needed because climatic conditions are highly variable;
- Further research for improving impact factors, models of fertilisers and of pesticides dispersion;
- Reduction of the use of mineral fertilisers and pesticides;
- Take into account the fate of pesticides in the fields;
- Include the quality aspect of the product;
- A well-defined functional unit (quantity + quality + duration);
- Take into account the biogenic carbon in the olive groves (olive tree permanent components);
- To remember that LCA is a multi-criteria analysis that assesses multiple environmental impacts.

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