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Review

Bibliometric Mapping of Research on Life Cycle Assessment of Olive Oil Supply Chain

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Abstract: The olive oil supply chain and even its individual stages have been extensively investigated through life cycle assessment (LCA) in recent decades. Most practices of the olive oil supply chain have been associated with negative environmental effects, such as soil degradation, carbon dioxide emissions, air and ground pollution, and depletion of groundwater. The current work aimed to perform a bibliometric analysis, through a science mapping approach, coupled with a review on the life cycle assessment (LCA) studies of the olive oil sector, with relevance to the environmental impacts of agricultural and industrial practices of this food sector. A total of 110 documents published in 2008–2021 were analyzed and discussed. More than 78% of documents were released from 2015. The main Scopus categories relating to the topic analyzed were environmental sciences (25%), energy (18%), and engineering (17%). The most productive countries were Italy, Spain, and Greece. The cluster analysis identified three main research topics related to the "agricultural phase", "oil extraction", and "waste management and by-product valorization". Most of the recent publications focused on the application of LCA to evaluate the environmental impact of innovative agricultural practices, sustainable control of parasites and weeds, wastes, and by-products valorization within a circular economy.

Keywords: bibliometric analyses; environmental impact; LCA; olive oil extraction; olive production; science mapping

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1. Introduction

The cultivation of olive trees (*Olea europaea* L.) is an ancient practice in the Mediterranean basin and the oil production represents a traditional and widespread activity of the agrifood sector in all the countries of the area. Known and used since ancient times, olive oil is the most used fat in the Mediterranean diet. Several clinical and epidemiological studies have highlighted the nutritional qualities of extra-virgin olive oil (EVOO), which is considered the most suitable fat for human consumption among all widely consumed dietary fats [1]. EVOO can have a series of benefits to human health because of its healthy fatty acid profile (particularly oleic acid), the high content of bioactive components including phenolic compounds (e.g., oleocanthal, tyrosol, hydroxytyrosol, oleuropein) and carotenoids (provitamin A, β-carotene, and lutein) [2].

Olive trees are cultivated in more than 50 countries distributed throughout the five continents for a total of 10.8 million hectares (average of the four-year period 2016–2019) [3]. The olive growing surface is mainly addressed to obtain drupes for the production of olive oil (about 87%), while the remainder produces table olives [4]. World olive production is mainly concentrated in the Mediterranean basin. The five countries with the largest olive growing area in 2019 were Spain, Tunisia, Italy, Morocco, and Greece [3]. As a result of an increasing globally olive oil demand, in 2016–2017, 162,000 hectares of olive groves were planted, and 100,000 hectares were transformed from traditional or intensive cultivation to the super-intensive system to satisfy market needs [4]. Current trends see an expansion of olive growing in areas such as South America, Argentina, and Australia; for example, in a few years Argentina and Australia have multiplied their production of olives, reaching 342,951 and 86,192 tons in 2019, respectively [3]. The top five olive oil producing countries, considering the average production of the four-year period 2016–2019, were Spain, Italy, Greece, Turkey, and Tunisia [3]. In Figure 1 the top ten countries with the largest olive growing area and related olive oil production are shown.

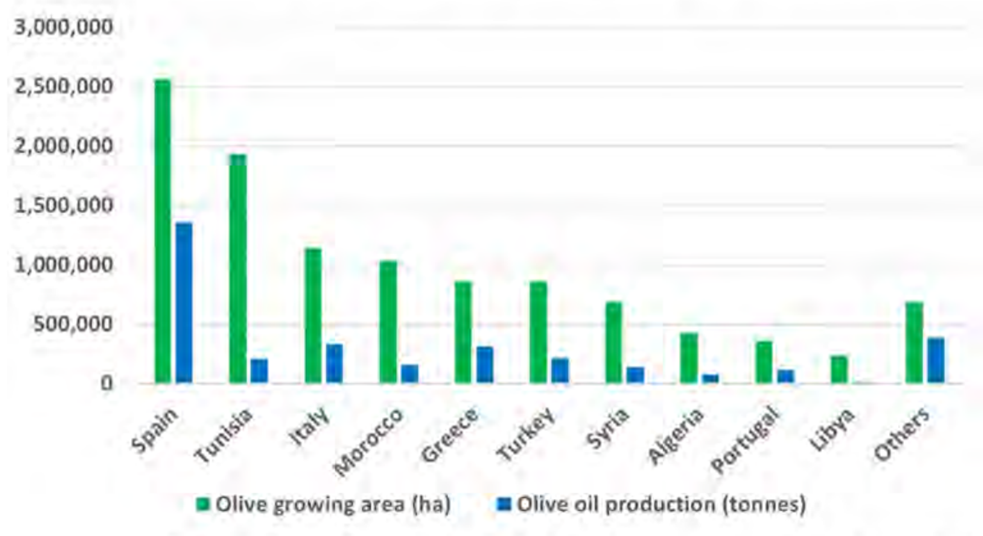

Figure 1. Top ten countries with the largest olive growing area and related olive oil production (means of the four years 2016–2019 [3]).

Most practices of the olive oil supply chain (from the extraction of raw materials, through the cultivation of olive trees and oil production, to the final management of wastes and co-products), particularly in the European Union (EU) countries, have been associated with various negative environmental effects, such as soil degradation and pollution, variation of soil microbial populations, harmful atmospheric emissions, pollution and depletion of groundwater [5]. The use of pesticides, herbicides, chemical fertilizers, irrigation, or inadequate management of mill wastes and by-products can generate high environmental impacts [6,7]. An important issue in the olive oil production sector is the management of the produced wastes. A large part of the organic wastes from mills is distributed directly on soils for its beneficial effects related to the nutrient concentration and its potential for mobilizing ions, but also with possible negative effects due to its high content of mineral salts and phytotoxic compounds [8,9]. The environmental impacts vary significantly according to the different agronomic techniques, cultivation systems, and oil extraction technologies adopted, correlated with the climatic, socioeconomic, and cultural conditions [10].

The potential environmental impacts associated with a system (product/process/activity) during its life cycle can be assessed using the life cycle assessment (LCA) methodology, through the recognition and evaluation of the resources consumption and the greenhouse gas emissions [11]. LCA analysis can be useful in identifying strategies for improving the environmental performance of a system in the different phases of its life cycle and in supporting strategic planning or design or redesign of products or processes [12]. Spatially referenced data should be considered when assessing the environmental impact of technological innovations by LCA in the context of the environmental risk assessment of European Union technology policies [13]. The earliest LCA studies, now considered partial LCAs, date back to the late 1960s and early 1970s, and the LCA methodology went through an initial period of conception in 1970–1990 and then standardization in 1990–2000 [14]. The LCA methodology is internationally regulated by the ISO 14040 and ISO 14044 standards [15,16]. For LCA studies in the specific sector of olive oil production, these regulations are accompanied by the product category rules (PCR) document relating to olive oil for the environmental product declaration "Virgin olive oils and its fractions" [17]. LCA has been widely adopted to evaluate the environmental sustainability of agriculture and food processing [18,19]. In recent decades, LCA has been applied in studies on the olive oil supply chain (production of olives, olive oil extraction, waste management) with the aim of identifying the more critical activities/processes in terms of environmental loads and to find improved strategies to limit the negative effect of the productive process [20]. One of the most cited publications in international journals on a complete LCA study on olive oil dates from 2008 and addressed the natural resource consumption and the environmental emissions associated with "cradle to gate" olive oil production including the agricultural and extraction phases [21]. Reviews on LCA of the olive oil sector were carried out by Salomone et al. [22] on a total of 51 papers, by Banias et al. [10] on 18 papers, and by Espadas-Aldana et al. [20] on 23 selected studies.

Quantity, quality, and trends of research activities of a research field or a specific topic within the scientific literature can be statistically analyzed by the bibliometric analysis approach, comprising performance analysis and bibliometric mapping (or science mapping) techniques [23,24]. The bibliometric analysis approach contributes to study the development and trends of a research field and enables analysis of publishing activities of individual research groups, institutions, or countries, to find connections between publications and research groups, to study the international dimension of a research field, to quantify the most cited publications and the most cited authors [25,26]. Several scientific databases, which also include patent and funding data, are used to retrieve bibliometric data to perform science mapping analyses. The studies based on bibliometric analyses are limited to the publications indexed under the selected scientific database and retrieved with the adopted search criteria. Research outputs from company activities or international projects may be overlooked when not reflected in publications in peer-reviewed journals. Despite its limitations, the bibliometric analysis method allows large amounts of bibliometric data to be summarized for presenting the intellectual structure and trends of a research topic. The three freely available bibliometric mapping software HistCite [27], CiteSpace [28], and VOSviewer [29] are packages widely used for performing automatic analyses of scientific research fields. In the past two decades several research areas have been widely analyzed by the science mapping approach (see review by Chen [26]). This bibliometric methodology was also used for mapping research developments and trends in individual crop species such as grape [30], fiber crops [31,32], sugarcane [33], rice [34], maize [35], hazelnut [36], durum wheat [37], potato [38], bread wheat [39], and muskmelon [40]. No bibliometric study has been published so far on the LCA research on the olive oil supply chain.

Due to the general increasing interest in agrifood supply chain sustainability and the several LCA studies published in the past decade on olive oil production, the current work presents a science mapping analysis of the scientific research, based on LCA, on the olive oil supply chain, coupled with a literature review with relevance to the environmental impacts of agricultural and industrial practices of this food sector. The aims of this study are primarily to provide a holistic overview of the development of the topic and to detect the prominent research topics and their trends over time. In relation to the latter point, the current study also provides a review of the main topics and issues found in literature. The novelty of this study is to identify and quantify the temporal and geographical patterns in the relevant literature, analyzing the number of publications per year and country that carried out the research, including research institutions and authors, where the research findings are published, and what are the major research topics and trends. The performed bibliometric analysis focuses on the study of data associated with Scopus indexed scientific publications, which are often the result of collaboration between teams of researchers and industrial partners during international or national projects. This paper can be useful as a guideline for scientists seeking to improve their understanding of the wider LCA research dynamics concerning the olive oil sector, with a focus on the management of olive growing and oil production wastes and on the valorization of by-products.

2. Materials and Methods

Elsevier's Scopus and Thomson Reuters' Web of Science are the most frequently used multidisciplinary databases for bibliometric analyses. In the present study, the Scopus database was chosen because it is considered as one of the largest repositories of abstracts and citations of peer-reviewed literature. In addition, 99% of Web of Science indexed journals overlap with Scopus, while only 34% of Scopus indexed journals are also indexed in Web of Science [41]. Bibliographic records related to olive growing and olive oil production were retrieved from the Scopus database on 30 December 2021.

Relevant scientific publications were identified by using the string (TITLE-ABS-KEY (LCA OR "Life Cycle Assessment" OR "Life Cycle Analysis") AND TITLE-ABS-KEY ("olive*")) AND (EXCLUDE (PUBYEAR, 2022)); i.e., by using the search parameters "LCA", "life cycle assessment", "life cycle analysis", and "olive" in the combined fields of title, abstract, and keywords. The search period was limited by excluding documents dated after 2021 to make comparisons of complete 12-month intervals. No starting date was given for the search, permitting the search database to find the earliest articles in the literature. A total of 148 papers were retrieved and first examined individually by carrying out a manual review based on document type and titles, abstracts, and keywords. The publications were selected by restricting the dataset to the document types of article, review, book chapter, note, and conference paper. Patents were not considered. Thirty-eight papers were found not to meet the selection criterion or not pertinent to the topic (olive and/or LCA were only mentioned and no data on LCA of olive oil were reported, LCA acronym not corresponding to "life cycle assessment", olive* equivalent to author names, LCA carried out on some foods containing olive oil such as canned anchovies) and then removed from the following analysis; the final database was composed of 110 documents. The first relevant document found was published in 2008; thus the period to which the publication dataset refers is 2008–2021. Studies on journals not indexed in Scopus, according to its dates of coverage, may be missing.

The productivity was measured according to the number of publications over the years, the research institutions, and the countries involved in the specific research area, the distribution of publication by journal and its citation impact, the identification of the most involved subject areas, the most cited papers. The VOSviewer software version 1.6.16 [42] was used for generating and visualizing bibliometric networks based on the 110 retrieved publications. Keywords co-occurrence was explored, and clusters were constructed by considering the terms occurring at least 3 times and a minimum of 30 terms per cluster. The appropriate VOSviewer software functionality was used to omit some terms not relevant for the analysis (article, case study, comparative study, controlled study, critical review, priority journal, procedures, review, surveys, country names, etc.). More detailed explanations about the cluster analysis and graphical map representation are available in the VOSviewer manual [43].

3. Results

Performance Analysis

As the Scopus search was conducted on 30 December 2021, some publications for 2021 may be missing because journal publisher metadata have not yet been processed for indexing the documents into the Scopus database. The first article was published in 2008 [21]. In the first half of the considered period (2008–2014), the number of documents per year varied from 0 to 10 with an average of 3.4 per year; the number of papers significantly increased in the second period (2015–2021) with a mean per year of 12.3 and a range from 8 to 18 (Table 1).

Table 1. Documents per year on life cycle assessment (LCA) of olive oil supply chain from 2008 to 2021.

Year	Number of Documents			Number of Authors	Number of Journals	Number of Countries	Number of Citations	
	Total	Articles on a Journal	Book Chapter—Conference Paper				Total	Average *
2008	1	1	0	2	1	1	96	96
2011	1	1	0	6	1	1	1	1
2012	3	3	0	11	2	3	201	67
2013	9	6	3	33	8	7	351	39
2014	10	8	2	44	9	5	349	35
2015	8	8	0	30	5	5	282	35
2016	14	13	1	61	11	10	424	30
2017	10	9	1	40	5	8	429	43
2018	9	6	3	28	7	4	175	19
2019	14	14	0	67	12	9	214	15
2020	13	12	1	56	12	13	78	6
2021	18	18	0	105	12	12	40	2

* Number of citations divided by the number of articles.

Most of the documents were published in peer-reviewed journals (n = 99, equal to 90.0%) and only a few documents were published on book chapters (n = 3), or on conference proceedings (n = 8). Ninety-nine documents (90.0%) were original research articles and eleven were reviews or state-of-art articles (10.0%). The number of authors and countries involved in LCA studies on olive oil supply chain experienced a progressive growth over the years and could be partly attributed to the rising interest in the research topic and to the current higher pressure to publish among academics.

The studies were published on 54 different journals and conference proceedings or books. Eleven journals published from two to four documents and only three journals more than four documents (*Journal of Cleaner Production*, *Sustainability*, *Journal of Environmental Management*). Table 2 reports the 14 journals publishing at least 2 papers and the relative Scopus CiteScore (CS), SCImago Journal Rank (SJR), and Highest CiteScore Percentile (HP) [44]. CS is a measure of the citation impact of scientific journals based on the citations number to papers by a journal over four years, divided by the number of the same papers indexed in Scopus. SJR is a bibliometric indicator of the degree of influence of a scientific journal. SJR measures weighted citations received by the serial and it is determined by the number of citations and by the importance of the journal from which the citation comes. The HP is based on the CiteScore metric and indicates the relative standing of a journal in the subject area where the source performs the best. The most active source of publications was the *Journal of Cleaner Production* with 30 publications (27.3%) out of 110 published papers on LCA. This international and transdisciplinary journal, focusing on cleaner production, environmental and sustainability research and practice, is characterized by having the highest SJR (1.937), ranking after *Energy* (1.961). The *Journal of Cleaner Production* has also the highest CS (13.1), followed by *Energy* (11.5), *Renewable Energy* (10.8), *Science of the Total Environment* (10.5), and *Journal of Environmental Management* (9.8). All these journals, together with the *International Journal of Life Cycle Assessment*, *Sustainable Production and Consumption*, *Sustainability*, *Biomass & Bioenergy*, *Foods*, and *Journal of the Science of Food and Agriculture* ranked in the 84th–98th CS percentile.

Figure 2 shows the Scopus subject areas in which the examined publications on LCA of olive oil production fall, bearing in mind that journals, particularly those that are multidisciplinary or deal with different aspects of the olive oil chain, are classified simultaneously in more subject areas. Numbers following the subject area name refer to the percentage and to the number (in brackets) of articles that fall into the subject area. The involved thematic areas are 19. As expected, the list is headed by the subject area environmental sciences (25%), followed by energy (18%), engineering (17%), business, management and accounting (12%), and agricultural and biological sciences (9%). Less represented areas were social sciences (4%), chemical engineering (3%), biochemistry, genetics and molecular biology (2%).

Table 2. Major characteristics of the top journals publishing LCA studies on olive oil production.

Journal [a]	Publisher	N. [b]	CS [c]	SJR [d]	HP [e]
Journal of Cleaner Production	Elsevier	30	13.1	1.937	98
Journal of Environmental Management	Elsevier	5	9.8	1.441	95
Sustainability (Switzerland)	Multidisciplinary Digital Publishing Institute (MDPI)	5	3.9	0.612	84
Science of the Total Environment	Elsevier	4	10.5	1.795	96
International Journal of Life Cycle Assessment	Springer	4	7.8	1.093	90
Foods	Multidisciplinary Digital Publishing Institute (MDPI)	4	3.0	0.774	93
Sustainable Production and Consumption	Elsevier	3	6.7	1.019	88
Chemical Engineering Transactions	Ital. Ass. Chem. Eng in. (AIDIC)	3	1.5	0.274	38
Acta Horticulturae	Inter. Soc. Hort. Science (ISHS)	2	0.5	0.181	12
Biomass And Bioenergy	Elsevier	2	6.7	1.037	94
Renewable Energy	Elsevier	2	10.8	1.825	88
Agronomy	Multidisciplinary Digital Publishing Institute (MDPI)	2	2.6	0.707	65
Energy	Elsevier	2	11.5	1.961	98
Journal of the Science of Food and Agriculture	Wiley-Blackwell	2	5.5	0.782	88

[a] Journals with at least two publications; [b] N.: number of documents; [c] CS: CiteScore 2020; [d] SJR: SCImago Journal Rank 2020; [e] HP: Highest CiteScore Percentile 2020 (a 98th CiteScore Percentile means that the journal is ranked in the top 2% of its subject area).

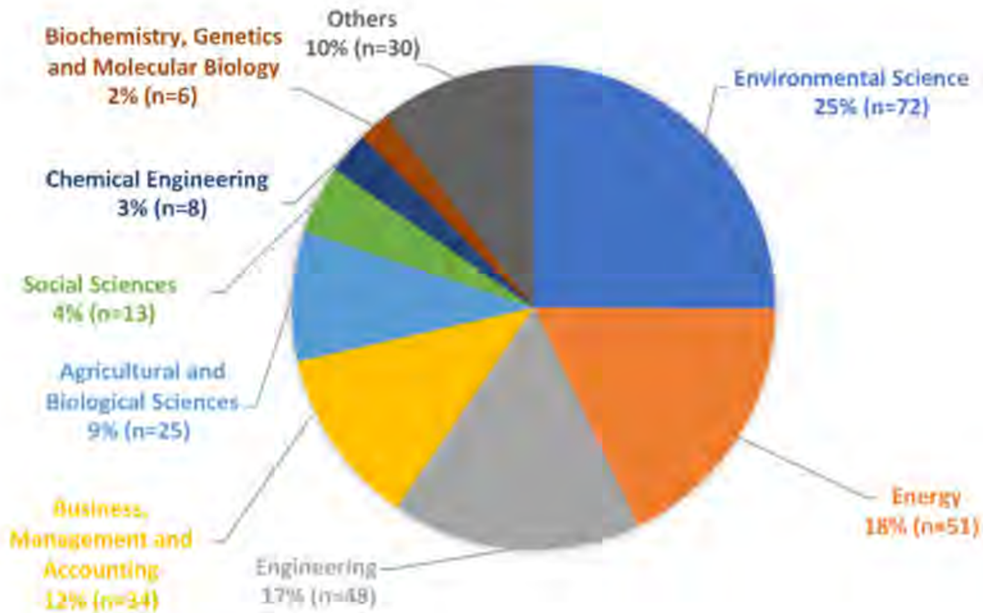

Figure 2. Scopus subject areas in which the examined publications on life cycle assessment (LCA) of olive oil production fall.

Regarding author attributes such as affiliation countries, 31 countries were involved in at least one article on LCA of olive oil production, but only 10 countries participated in at least three papers (Figure 3). The world situation shows that Italy was the most active country involved in 53.6% (n = 59) of total publications (n = 110), followed by Spain with 18.2% (n = 20), and this can be related to the fact that these two leading countries have the largest production of olive oil (Table A1). Greece published ten papers, France six papers, Cyprus and Iran five papers, Australia, Netherlands and Tunisia four papers, and Portugal three papers.

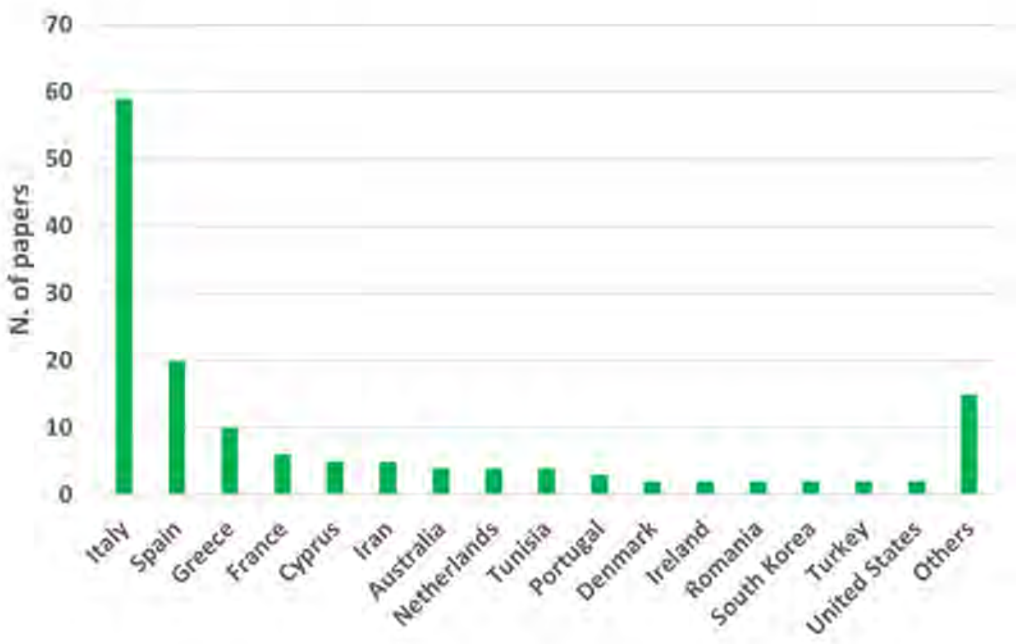

Figure 3. Author affiliation countries publishing at least 2 papers on LCA of olive oil production.

The cooperative network of key authors based on the number of documents on LCA of olive oil supply chain published by authors is reported in Figure 4; the main characteristics of the most active institutions are reported in Table A2. The cooperative network indicates the collaborations between authors in terms of number of papers with coauthors belonging to the nodes interconnected. Authors of at least two papers were considered to develop the map. The map shows many groups working on LCA of olive oil production that are not connected to each other. This is explained by the fact that most of the experiments were conducted in local contexts and by the availability of secondary data in LCA databases implemented in the LCA studies. The largest network (red cluster) with 12 components has its center at the Mediterranean University of Reggio Calabria, Italy, where the most relevant authors, who have published 7–10 papers each, work in the same research group. The second major network (dark green cluster) with 9 components has the University of Milano, Italy, as its header, and the authors participating in at least 4 publications work in the same research group. Other institutions participating in at least four articles were the University of Perugia (Italy), University of Bari Aldo Moro (Italy), University of Basilicata (Italy), Frederick University, Nicosia (Cyprus), University of Toulouse (France), INRAE Occitanie-Toulouse (France), University of Catania (Italy), University of Foggia (Italy), University of Messina (Italy), University of Sassari (Italy), and University of Jaen (Spain). It is notable that the most productive institutions belong to EU countries of the Mediterranean basin, and this is partly consistent with the importance that olive growing, olive oil production, and EVOO per capita consumption have in these nations [1,4]. The low presence of research institutions from other important olive oil producing countries of North Africa and Near East could be due to the minor research funds available to those institutions and to the minor pressure on academics to publish in indexed journals.

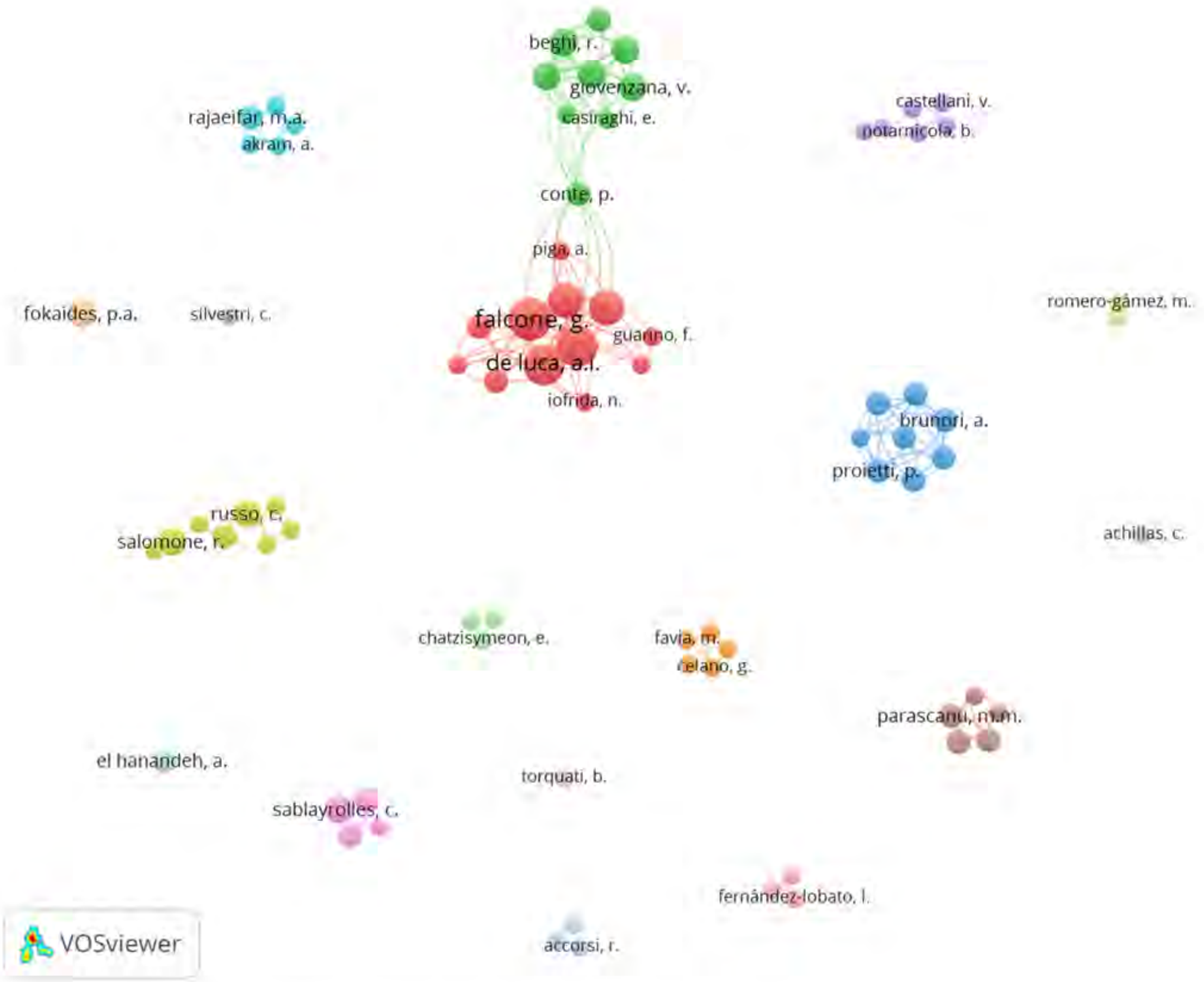

Figure 4. Cooperative network of key authors.

4. Principal Topics and Trends of LCA of Olive Oil Production Research

The cluster analysis of terms related to the field present in the keywords, title, and abstract of 110 publications published on LCA of olive oil supply chain in the period 2008–2021 is illustrated in Figure 5. A total of 123 keywords, with a minimum number of occurrences of 3, are grouped in three main clusters (each with a minimum of 30 keywords), which provide an overview of the structure of the research themes. Different colors (red, green, blue) represent the terms (keywords) belonging to different clusters. The size of the nodes (circles) is based on the number of occurrences. Links between nodes indicate the co-occurrence between terms. The red cluster mainly refers to the agricultural phase (olive tree cultivation and olive harvesting); the blue cluster is inherent to the oil production in the mill; the green cluster concerns the waste management, the by-product valorization (waste from orchards, olive mill wastewater, olive husk, pomace, olive wet husk) and the oil packaging and distribution, with a view to transitioning to a circular economy. The three clusters are tightly interconnected because some aspects of the olive oil chain of research can be included in more than one cluster.

4.1. Agricultural Phase

The red cluster consists of 55 keywords; high-frequency keywords are "carbon footprint", "climate change", "cultivation", "agriculture", "agricultural practices", "machinery", "land use", "productions". This cluster includes publications that evaluated the environmental impact of all activities of the agricultural phase (young olive planting, pruning, soil management, fertilization, irrigation, weed control, pesticide treatments, fruits harvesting). Various factors were considered by the numerous LCA analyses, such as the diesel and electricity consumption needed for the different cultivation practices (soil management, pruning, olive harvesting, olive transport), water consumption for irrigation, production, transport, and use of fertilizer, pesticide, and herbicide products. Several studies were addressed at evaluating the impact of one or more activities/processes of the agricultural phase alone, while other studies also considered the activities/processes of the other phases of the supply chain. However, the studies focused on agricultural phase paid particular attention to three areas: growing systems, plant protection, and harvest.

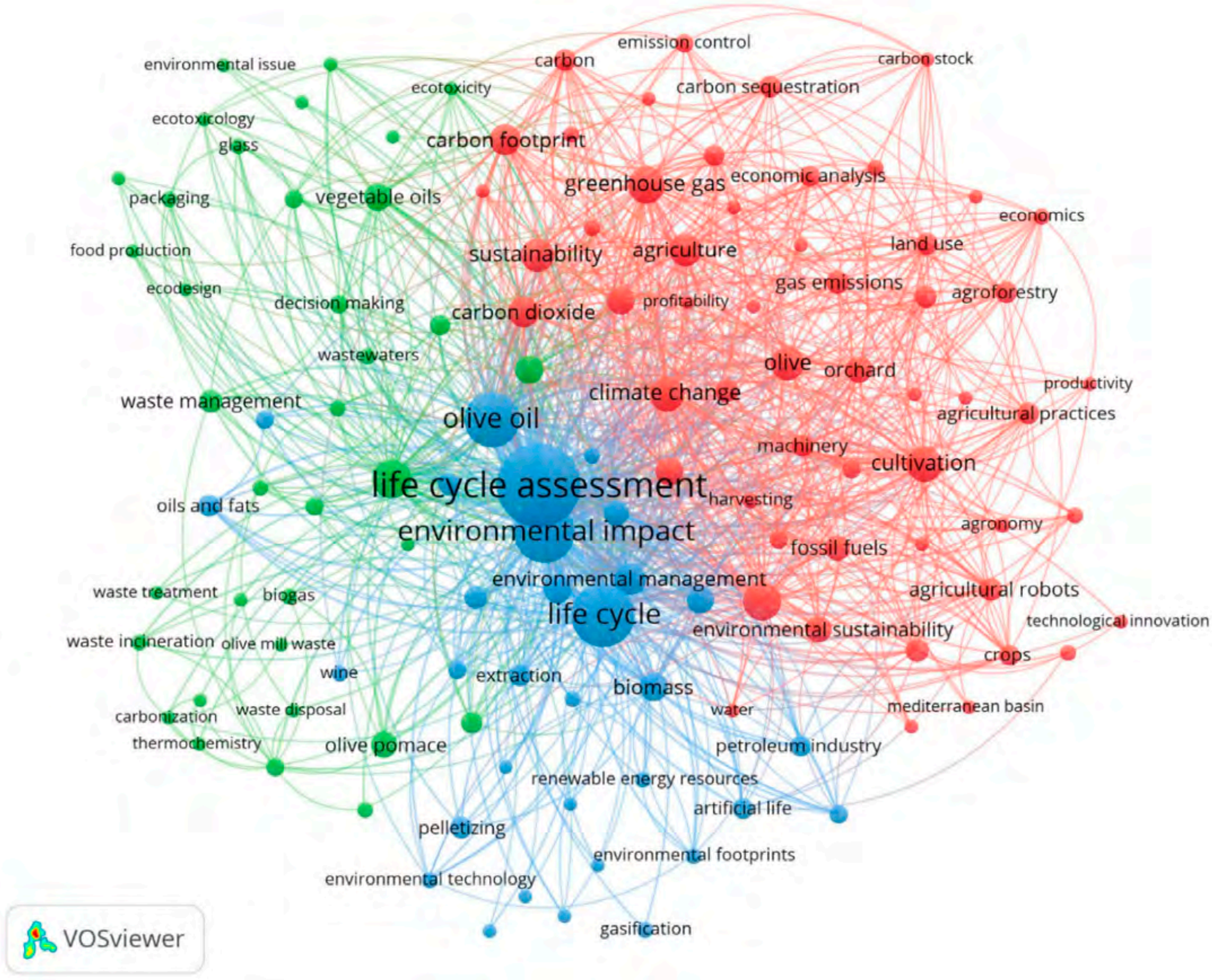

Figure 5. Terms map based on LCA of olive oil production publications from 2008 to 2021.

4.1.1. Growing Systems

Conventional, organic, or integrated cultivation techniques, and different olive-growing models (traditional, intensive, and super-intensive) were the focus of numerous studies. Comparison between traditional and organic olive growing systems showed a significant decrease of greenhouse gas emissions (carbon footprint per kilogram of product of 324 and −10 g CO_2 eq, respectively) of agricultural practices in the organic system, mainly due to the higher efficiency in reducing the impact on fossil fuel depletion [45]. Optimization of fertilization in the organic system was considered a priority because of the higher costs and higher environmental impact caused by manure fertilization compared to foliar fertilization in the respiratory inorganics (15.759 vs. 12.316 pt), climate change (4.706 vs. 1.882 pt) and eco-toxicity (1.063 vs. 0.321 pt) impact categories [46]. Comparison of environmental impact assessment of intensive and super-intensive growing systems versus traditional ones was the focus of many studies. The intensive and super-intensive irrigated systems can allow a higher level of mechanization (pruning and harvesting), higher productivity, and higher agronomic and economic-efficiency rates than the traditional farming systems, but they showed the largest impact on most environmental impact categories (specifically in the climate change and acidification categories) because of the higher use of fertilizers, plant protection products, herbicides, and soil management [47–51]. Water use is increasingly considered relevant with climate change. In recent decades, the number of scientific studies developed through the application of different methods to assess it has increased significantly in the context of sustainable agriculture [52]. Some studies compared differences in irrigation management [49,51,53,54]. Maesano et al. [54] pointed out that a non-irrigated (NI) system showed the best environmental performance compared to a partial (PI) and a fully irrigated (FI) system, due to not using the water resource and less energy inputs. Irrigation represented one of the main hot spots for most of the examined impact categories, and specifically for the water consumption category, with values of 8.02×10^{-4} m^3 for NI, 1.97×10^{-1} m^3 for PI, and 1.15×10^{-1} m^3 for FI in the Life Cycle Impact Assessment through the ReCiPe Midpoint method (per kg of olive production). Some other studies considered the use of deficit irrigation in the olive tree more environmentally and economically sustainable than irrigated olive cultivation, and specifically recommended it when water resources are scarce or expensive [55,56]. This is strictly in line with sustainable development models promoted by the recent international program "The European Green Deal" [57]. A comparative environmental LCA in rainfed and irrigated orchards highlighted the importance of water management based on an irrigation decision supporting system (DSS) compared to conventional irrigation practices based on farmer experiences in order to decrease the negative environmental impacts of olive cultivation; a reduction of water and energy use by 42.1% was found with DSS-based irrigation management compared to conventional practices, resulting in a reduction of the total environmental impact of 5.3% per unit of product (1 ton) and 10.4% per unit of area (1 ha) [58]. LCA and energy-economic analysis, performed to compare the conventional system with an alternative management of olive orchards in semi-arid environments (drip irrigation with treated urban wastewater and agronomic techniques aimed to preserve soil quality) showed that the alternative management was the most energy-consuming system (total input energy per kg of olives 4.43 and 2.80 MJ, respectively), but it resulted in a more effective management model in terms of emissions of CO_2 eq (0.08 kg compared to 0.11 kg), productivity and profitability [59]. The environmental performance of conventional energy sources (electric and fossil) and the hybrid photovoltaic source for irrigation systems in intensive and super-intensive olive orchards were investigated; a significant saving of fossil energy (up to 67%) and a consequent reduction of greenhouse gas emissions by the photovoltaic installation were shown [60]. Overall, the organic systems showed lower environmental impacts than the conventional ones because of the lower use of fertilizers and pesticides, but they were characterized by lower yield and higher costs [49]. Considering both the environmental and productivity aspects, the integrated production systems related to the soil management, irrigation, phytosanitation, and harvesting would be the best olive fruit production system and a sound strategy to achieve a positive carbon balance [49,50].

4.1.2. Plant Protection

Several studies considered the environmental impact of all phases of the olive oil chain (from trees cultivation to oil production, packaging, and distribution), and showed that the most significant environmental problems arise from the agricultural phase, mainly due to fertilizer and pesticide treatments, and to the weed control [21,61–66]. Among chemicals, dimethoate-based insecticides were the most used [21,61], and seem particularly relevant in terms of freshwater consumption (about $\frac{1}{4}$ of overall consumption). In terms of greenhouse gas emissions, plant protection treatments were the most significant item in both conventional cultivation and organic cultivation, and number of treatments carried out seems a key factor due to fuel use [64]. In fact, besides the use of few chemicals for protection in organic farming, the large quantities and frequency of treatments causes an increase in the impacts associated with the plant protection phase. With regards to weed control, LCA showed better performance for most of the selected impact categories in the low-dosage/no-tillage scenario (reduced use of chemicals) than the zero chemical weeding control in the organic system and the traditional olive growing systems using chemicals for weed and pest control [67].

4.1.3. Harvest

Investigations of technical, economic, and environmental aspects of different olive harvesting systems (highly mechanized harvesting, mechanical-aided harvesting, fully manual harvesting) showed that mechanical harvesting was the best system for decreasing the production costs; the assessment of the environmental impact indicated that the entirely manual and mechanical-aided harvesting systems were the most sustainable in terms of impact per hour, while highly mechanized harvesting was less environmental impacting in term of mass-based unit (1 kg of harvested olives) when compared to the mechanical-aided harvesting system [68,69]. Previously, a study [46] showed that the mechanized harvesting had a higher environmental impact associated with the higher fuel consumption of the harvesting machines compared to the manual or semi-mechanized performance of harvesting, which, however, showed higher costs. The energy consumption was measured by Fantozzi et al. [70] for different olive harvesting techniques and the harvesting with electric rakes showed savings of about 100 kg CO_2 eq/ha, compared to the mechanical harvester. High values in the eutrophication (6.21 kg P eq) and climate change (3.09 kg CO_2 eq) categories were shown by the harvesting practices in the intensive olive growing systems because of the gas emissions caused by the diesel needed for the transportation of the materials used for the olive harvesting; a reduction of the environmental impact could be obtained by the substitution of diesel with eco-friendly fuels [49].

4.2. Oil Extraction

The blue cluster, including 32 keywords, mainly represents terms inherent to the oil extraction process. "Life cycle assessment" and "olive oil" are obviously the crucial terms corresponding to the keywords used for the bibliographic search; other important terms were "oil and fats", "extraction", "food products". LCA analysis applied to the oil extraction phase resulted in lower environmental impact and primary energy use compared to the agricultural phase [21,63,64]. The current oil extraction technologies are characterized by low variability, because the virgin olive oil extraction is essentially carried out through mechanical means: the traditional press, the three-phase centrifugation, and the two-phase ecological decanter systems. The traditional and continuous three-phase processes can produce large quantities of vegetable wastewater (96 L/100 kg olives) and wet pomace (54 kg/100 kg of olives), while the two-phase cycle extraction system generates a small volume of vegetable wastewater (5–25 L/100 kg of olives) and a high quantity of pomace with a water content between 55% and 60%. [71]. A lower impact was observed in the traditional olive oil extraction process compared to the two-phase and three-phase systems [72]. A study by Salomone and Ioppolo [61] showed that the three-phase centrifugation system allows a higher oil extraction capacity than the traditional pressing systems but requires a greater amount of water and energy; a modified system using continuous centrifugation with a two-and-a-half-phase system requires the addition of a small amount of water to dilute the olive pasta during the continuous centrifugation, enables the generation of an olive wet pomace containing part of the vegetation water, and consequently the generation of a smaller amount of wastewaters. The introduction of a physical co-adjuvant (calcium carbonate) during EVOO extraction allowed the reduction of operational time (around 33.5%), environmental impacts (1.58×10^{-1} and 1.78×10^{-1} kg CO_2 eq for the w/Calcipur®5 and the control, respectively) and costs (5%) [73], while the electroporation-assisted extraction improved the olive extraction yield of 5% and reduced the environmental impact indicators by approximately 5% [74]. LCA applied to an innovative olive mill plant with low oxidative impact, heating of paste, and a special decanter that avoids the vertical centrifugation showed the higher quality of EVOO but a higher environmental impact for all the categories considered (on average equal to 5%) compared to the conventional plant [75]. The use of visible and near infrared spectroscopy for the prediction of intact olive ripeness resulted in a lower environmental impact than chemical analyses; a saving of 11,360 kg CO_2 eq per year per laboratory was hypothesized by substituting the chemical analyses with the optical one [76].

4.3. Waste Management and By-Product Valorization

This cluster included 36 keywords related to the waste management of the whole olive oil supply chain including the agricultural phase, the oil extraction phase, and the oil packaging and distribution. High-frequency keywords were "waste management", "recycling", "olive pomace", "food products", "vegetable oils", "packaging", "glass", "ecodesign", "ecotoxicity", "wastewaters", "biogas", "waste incineration", "anaerobic digestion", "carbonization", "waste disposal", food waste", "solid waste".

The olive oil industry wastes include the olive tree pruning residues, pomace, de-oiled pomace, husks, pits, ashes, and wastewaters. Olive farms produce large quantities of wood from pruning which are usually eliminated through combustion and, in some contexts, the ash is reused as fertilizer. After extracting the extra virgin olive oil and the olive oil, the residues of the pressing consist of the olive mill wastewaters (OMW) and the wet pomace, which includes the husks, the pulp residues, and the olive pits. OMW essentially consists of water from oil olives, dilution water from oil pastes used in continuous systems, and soluble substances dissolved in the drupes. In some countries, the controlled direct spreading of OMW, or the produced sludge after OMW evaporation in storage ponds, on agricultural land is authorized as ferti-irrigation. The pomace undergoes successive and different processes from which it is possible to obtain pomace oil, of lower quality than olive oil but suitable for many foods and non-food uses. Oil can also be extracted from olive husk with hexane or other specific solvents. Exhausted or de-oiled olive pomace, and pits from virgin and exhausted pomace, are used as biomass to produce energy. OMW with olive pomace, olive wet pomace, and other agricultural wastes are also used to obtain compost.

4.3.1. Renewable Energy

The sustainable management of wastes for energy production has been the major research topic from a circular economy perspective. Several studies have investigated the environmental impact of the thermo-chemical conversion of solid and liquid olive mill wastes (pomace, mill wastewater, de-oiled pomace, husk, pits) by different pyrolysis systems, gasification, and combustion to produce biogas and biomethane [77–88]. A significant reduction of carbon emissions of the different pyrolysis systems, compared to with conventional waste management, was observed. An LCA study showed a global environmental impact reduction of 88.1% by the anaerobic digestion of olive mill solid waste for biogas production and a stabilized digestate in comparison to pomace oil extraction using natural gas as fuel [81].

Comparison of the conventional olive oil production system with two olive biorefinery platforms using olive wastes showed the production of some value-added bioproducts (oil pomace, biodiesel, fuel additive, phosphate salts) and the mitigation of the environmental impacts; the production of 1 ton of olive oil in the agro-biorefinery systems was associated with a 4.1–10.6% saving in the climate change damage category, 6.7–11.2% saving in energy consumption, and 1.6–12.0% saving in damage to human health [85]. Other studies concerned the manufacturing of briquettes and pellets for water heating and home heating [89–93]. LCA of pelleting process showed an improvement of about 85% in selected environmental impact categories in the manufacturing of olive husk pellets by exploitation of solar thermal collectors [90]. All these studies remarked on the advantages of using farm and oil industry by-products to produce renewable energy to enhance farm sustainability and noted they were capable of producing benefits for farmers and the whole community.

4.3.2. Other Studies on by-Product Valorization

Some other research concerned the potential environmental impact associated with the addition of olive pomace and olive stone flour in manufacturing artificial lightweight aggregates (LWA) and porous fired clay bricks. A reduction of about 3.8–15.3% of all the studied impact categories was found by substituting the clay with "alperujo" (a solid olive-mill by-product) with LWA manufacture [94], while the environmental benefits were limited for the production of ceramic bricks incorporating alperujo compared to the traditional ceramic brick manufacturing process [95]. The utilization of OMW in the brick-making process showed a decrease of the global warming potential (up to 3.1%) and of the abiotic depletion of fossil fuels (4.3%) with respect to the conventional fired clay brick production [96].

Other environmental assessments concerned the use of de-oiled pomace for weed control [97], the composting of olive mill waste [77,98], the use of olive by-product silages in the diet of dairy goats [99], the selective recovery of phenolic compounds (total phenols, hidroxytyrosol, tyrosol) with antioxidant properties from olive mill wastewater [100–102], the preparation of activated carbon from olive-waste cakes [103,104], the production of olive oil for cosmetic application from olive stones [105], the growth of microalgae in OMW to remove organic pollutants [106], and advanced oxidation processes for OMW treatments [107].

4.3.3. Packaging and Distribution

This cluster also includes some specific LCA analysis of olive oil packaging and distribution. Some studies discussed the environmental performances of different materials used for olive oil primary packaging (glass, tin, polyethylene terephthalate steel, Doypack) [108–111] and the relevance of the manufacture of glass bottles within the transformation stage [65,112]. A recent LCA study estimated environmental effects ranging from 2% to 300% in the packaging phase depending on the type of material used for the oil packaging and the impact categories taken into consideration [111]. Dimmed glass bottles, which are perceived to be of higher quality and the most environmentally sustainable by consumers [111,113], resulted in the most impactful packaging system due to their weight (58%) across all categories compared to tin (37%) and PET (13%) [111]. However, considering the distribution distance, the lowest environmental impact was shown by glass bottles in local distribution and by tin-plated cans in long-distance distribution cases [110]. The recyclable PET bottle could potentially have the lowest impact on global warming as a function of the possible advancements and improvement of PET recycling processes [108]. Innovative olive oil single-use plastic packaging (two layers of polylactic acid treated with metallization and one of bio-polyethylene) showed a better performance in the climate change category (-44% CO_2 eq) but had higher impacts in the ecosystem quality impact categories compared to the traditional one (three layers of polyethylene, aluminum, polyethylene terephthalate) [114].

5. Research Trends

Seventeen research articles (not including reviews or state-of-art papers) that have received more than a total of 50 citations and a minimum average value of 7 citations per year are reported in Table 3. Analysis of these papers provides insight into the topics that most attract research interest: resource consumption and carbon emissions from the olive oil industry, oxidation processes for olive mill wastewater treatment, innovative and sustainable olive-growing models, optimization of organic and conventional olive agricultural practices, and environmental evaluation of biomass pelleting. The top three articles received more than 90 citations and they were all published in the *Journal of Cleaner Production*. The most cited paper (219 citations) was published in 2017 by two research groups working at the University of Bari, Italy, and at the Institute for Environment and Sustainability, Ispra, Italy [115]. LCA was applied to some food products, including olive oil, to evaluate the environmental impacts associated with food consumption in EU-27 countries in 2010. Results indicated that the agronomic and zootechnical activities were the lifecycle phases with the highest impact for all examined foods, followed by the food processing and logistics phases. The burden of the end-of-life stage was often greater than those of the agriculture, transports, and processing phases. The second most cited paper (114 citations) was published in 2012 by researchers from the University of Messina, Sicily, Italy [116]. The potential environmental impacts of all activities involved in the olive oil production chain (olive farming, olive oil extraction, olive oil mill waste treatment) were assessed to design an efficient olive oil chain with low environmental impacts, and to use LCA as a chain-focused management tool. The critical activities associated with important environmental loads were conventional cultivation practices, fertilization, the use of pesticides, the combustion of exhausted pomace, and the co-composting of olive wet pomace with manure on fields. The third most cited paper with 96 citations, published in 2008 by researchers working at the University of Cyprus, Cyprus, deals with the natural resource consumption and environmental emissions associated with "cradle to gate" olive oil production [21]. To identify the processes with the most significant environmental burdens, LCA methodology was applied to the used fertilizers and pesticides, to farming activities, industrial oil extraction, oil transportation, and oil waste management. The production of the inorganic fertilizers used in olive tree cultivation and the practice of disposing of liquid waste from mills in evaporation ponds were found to be of primary importance with regard to raw material consumption, air pollution, and groundwater contamination.

Table 3. Published papers that received more than a total of 50 citations and at least an average value of 7 citations per year (30 December 2021).

Year	Authors	Countries [a]	Title	Journal	TC [b]	Avg. C [c]
2017	Notarnicola B., Tassielli G., Renzulli P.A., Castellani V., Sala S. [115]	Italy	Environmental impacts of food consumption in Europe	Journal of Cleaner Production	219	44
2012	Salomone R., Ioppolo G. [61]	Italy	Environmental impacts of olive oil production: a life cycle assessment case study in the province of Messina (Sicily)	Journal of Cleaner Production	114	11
2008	Avraamides M., Fatta D. [21]	Cyprus	Resource consumption and emissions from olive oil production: a life cycle inventory case study in Cyprus	Journal of Cleaner Production	96	7
2013	Chatzisymeon E., Foteinis S., Mantzavinos D., Tsoutsos T. [107]	Greece	Life cycle assessment of advanced oxidation processes for olive mill wastewater treatment	Journal of Cleaner Production	86	10
2012	De Gennaro B., Notarnicola B., Roselli L., Tassielli G. [47]	Italy	Innovative olive-growing models: An environmental and economic assessment	Journal of Cleaner Production	76	8
2014	Mohamad R.S., Verrastro V., Cardone G., Bteich M.R., Favia M., Moretti M., Roma R. [46]	Italy	Optimization of organic and conventional olive agricultural practices from a life cycle assessment and life cycle costing perspectives	Journal of Cleaner Production	75	9
2018	De Luca A.I., Falcone G., Stillitano T., Iofrida N., Strano A., Gulisano G. [67]	Italy	Evaluation of sustainable innovations in olive growing systems: a life cycle sustainability assessment case study in southern Italy	Journal of Cleaner Production	72	18
2013	Kalogerakis N., Politi M., Foteinis S., Chatzisymeon E., Mantzavinos D. [101]	Greece	Recovery of antioxidants from olive mill wastewaters: a viable solution that promotes their overall sustainable management	Journal of Environmental Management	70	8
2015	Aguilera E., Guzmán G., Alonso A. [45]	Spain	Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards	Agronomy for Sustainable Development	69	10

Table 3. *Cont.*

Year	Authors	Countries [a]	Title	Journal	TC [b]	Avg. C [c]
2014	Rajaeifar M.A., Akram A., Ghobadian B., Rafiee S., Heidari M.D. [62]	Iran	Energy-economic life cycle assessment (LCA) and greenhouse gas emissions analysis of olive oil production in Iran	Energy	63	8
2016	Rajaeifar M.A., Akram A., Ghobadian B., Rafiee S., Heijungs R., Tabatabaei M. [117]	Iran, Netherlands	Environmental impact assessment of olive pomace oil biodiesel production and consumption: a comparative lifecycle assessment	Energy	60	10
2016	Paolotti L., Boggia A., Castellini C., Rocchi L., Rosati A. [118]	Italy	Combining livestock and tree crops to improve sustainability in agriculture: a case study using the life cycle assessment (LCA) approach	Journal of Cleaner Production	59	10
2019	Boesen S., Bey N., Niero M. [113]	Denmark	Environmental sustainability of liquid food packaging: is there a gap between Danish consumers' perception and learnings from life cycle assessment?	Journal of Cleaner Production	53	18
2015	Accorsi R., Versari L., Manzini R. [108]	Italy	Glass vs. plastic: life cycle assessment of extra-virgin olive oil bottles across global supply chains	Sustainability (Switzerland)	52	7
2016	Kylili A., Christoforou E., Fokaides P.A. [90]	Cyprus	Environmental evaluation of biomass pelleting using life cycle assessment	Biomass and Bioenergy	52	9
2017	Benavente V., Fullana A., Berge N.D. [79]	Spain, United States	Life cycle analysis of hydrothermal carbonization of olive mill waste: comparison with current management approaches	Journal of Cleaner Production	50	10
2015	Tsarouhas P., Achillas C., Aidonis D., Folinas D., Maslis V. [63]	Greece	Life cycle assessment of olive oil production in Greece	Journal of Cleaner Production	50	8

[a] Countries of the authors' institutions; [b] TC: total number of citations; [c] Avg. C: average number of citations per year.

The term year map, based on all the 110 publications on LCA applied to the olive oil supply chain retrieved from the Scopus database (2008–2021), is reported in Figure 6. The aquamarine terms are the keywords more frequently used in early LCA publications ("waste management", "waste treatment", "wastewaters", "environmental issues", "carbon sequestration", "carbon dioxide"). During this period (2008–2014), LCA was mainly addressed to analyzing the environmental impact of resource consumption and carbon dioxide emissions from the olive oil industry, waste management, strategies aimed to improve recycling and reduce negative environmental effects, and sustainable energy-production from solid wastes [21,77,119]. That was accomplished through a better understanding of the environmental impacts of the different olive growing and oil extraction processes and the diagnosis of related environmental hot spots [46,47,59,61,112].

This first period was followed by publications with 'hot' terms such as "environmental sustainability", "carbon footprint", "global warming" "gas emission" "cultivation", "orchard", "pelletizing", "packaging", "oil and fats" (terms in green, Figure 6). The greater attention of consumers towards environmental issues stimulated research on the environmental sustainability of the agrifood supply chains, on the identification of production phases with greater negative effects on the environment, and on the recycling, use, and valorization of oil industry by-products from a circular economy perspective. LCA analysis concerned the environmental impact of land use for traditional and organic farming, the sustainable development of olive tree cultivation and EVOO industry, the energy efficiency of agricultural practices, the biomass uses for the energy production, and the different materials for oil packaging [63,64,79,90,111,120].

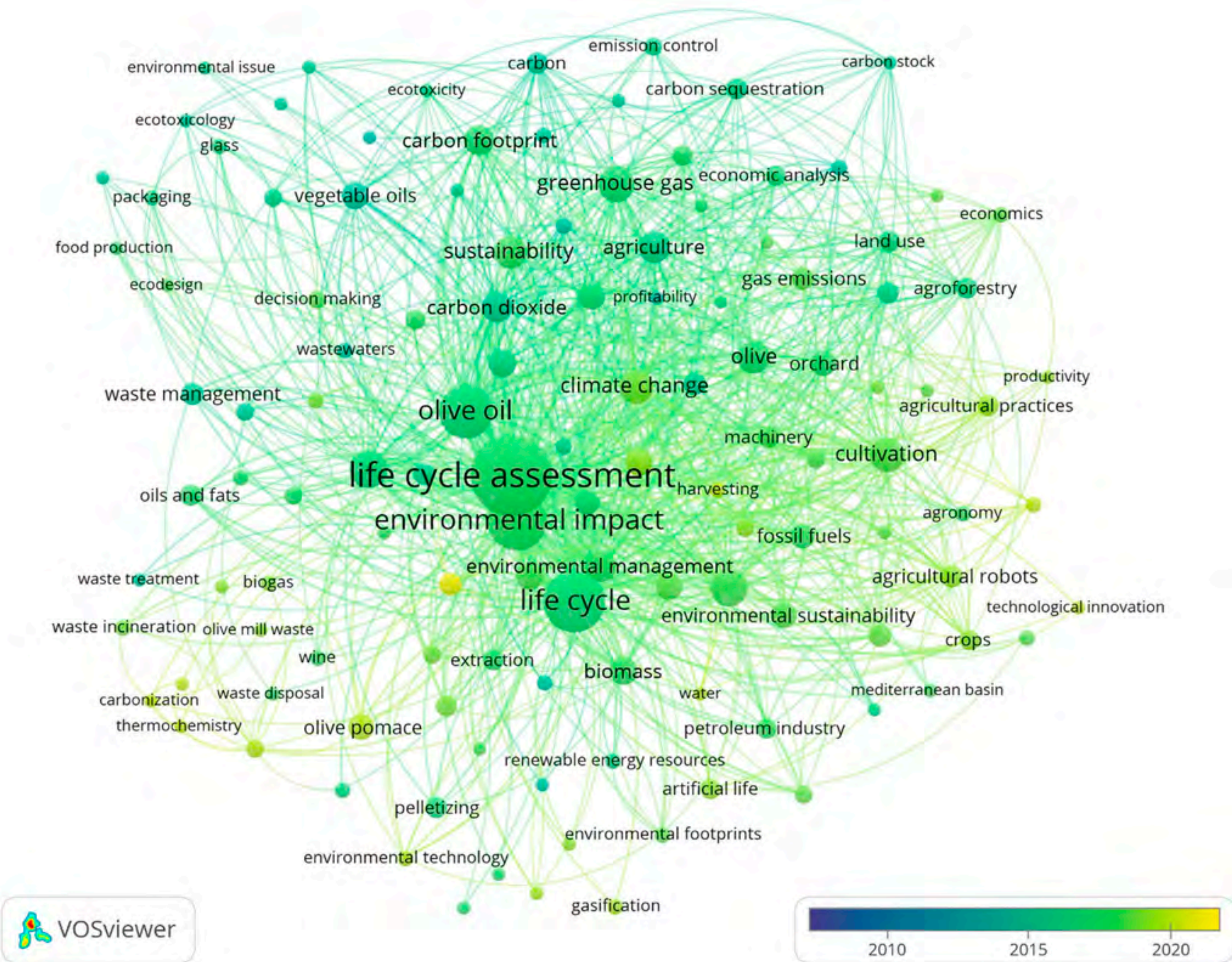

Figure 6. Term year map based on all the Scopus publications on LCA applied to the olive oil supply chain. The blue, green, and yellow colors represent, respectively, earlier, medium, and more recent terms mostly present in the scientific publications.

Yellow terms (Figure 6) represent those covered in more recent publications (2018–2021) ("productivity", "agricultural practices", "harvesting", "irrigation", "olive pomace", "anaerobic digestion", "gasification", "circular economy", "technological innovations"). Much research concerned the environmental impact of the super-intensive olive growing systems, innovative agricultural practices aimed to improve olive productivity, alternative agronomic practices for maintaining soil fertility or supplying nutrients to the soil, the sustainable control of parasites and weeds, assisted and fully mechanized olive harvesting to reduce the costs, the different systems of anaerobic digestion of olive and oil industry wastes for biogas production, and cost-benefit analysis of technological innovations for olive oil production by-products valorization [50,51,65,69,73,75,86,121].

These LCA research topics have received a strong impetus from the recommendations of the European Commission on the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis [122], on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations [123], and on the guidance for the implementation of the EU Product Environmental Footprint (PEF) [124]. Fully exploiting the potential of agriculture to mitigate climate change by increasing the sector's positive contribution to carbon sequestration is one of the challenges of the European Common Agricultural Policy 2014–2020. The olive oil production sector can be an important tool against climate change, particularly in countries where olive trees are widely cultivated. Some studies have focused on proper olive crop management practices to mitigate the release of CO_2 into the atmosphere through carbon immobilization [120,125], also as a result of international European projects on climate change mitigation [126,127].

6. Conclusions

Life cycle assessment represents a useful methodology for evaluating the environmental performance of the different phases of the olive oil supply chain, to verify the ecological effectiveness of different design choices, to evaluate the related economic aspects, and therefore for an integrated assessment of the sustainability of the olive oil sector [22]. Through bibliometric methods, 110 publications related to the LCA of olive oil supply chain stages were retrieved from the Scopus database and examined (2008–2021). The current bibliometric analysis highlighted the recent application of LCA to the olive oil sector as a growing research topic, which has led to a notable scientific literature in recent years (86 out of the total 110 published documents on the topic fell in the second half of the analyzed period). This is in line with the increased interest in the sustainability of agriculture and food production systems shown by most countries [128] and is consistent with the growing interest of consumers worldwide in EVOO [129]. The papers were published in a total of 54 journals that are classified into 19 subject areas. The high environmental impacts of the agricultural phase, and the relevance of problems related to the waste management of the whole chain, prompted researchers in publishing on journals qualified in environmental issues and falling mainly in the subject area of environmental sciences, with a record of 72. The energy and engineering subject areas ranked second and third with 51 and 48 records, respectively. The most productive journal was the *Journal of Cleaner Production*, (27.3% of the documents on LCA of olive oil production were published in this journal), followed by the *Journal of Environmental Management* (4.5%) and *Sustainability* (4.5%). The trend is to publish in indexed journals (90%) rather than conference proceedings or book series (10%). Many groups are found to have worked on the LCA of the olive oil sector, with limited linkages and international collaboration. The environmental impacts of the olive oil industry were analyzed and evaluated in several territorial contexts. The current bibliometric analysis has highlighted that, considering the top ten countries for olive oil production and olive oil consumption, a large part (62.5%) of the scientific literature on LCA of olive oil supply chain has been developed in the EU countries (Italy, Spain, Greece, France, Netherlands, and Portugal) compared to the other top producing countries of the Near East (Syria) and North Africa (Morocco, Tunisia, Turkey, Algeria, Egypt) which participated in six (4.1%) documents. This may at least in part be attributable to EU agricultural policies and to the greater sensitivity and attention of EU populations to the issues of environmental sustainability of agriculture and food production.

The cluster analysis identified three main research topics that the research groups worked on: “agricultural phase”, “oil extraction”, and “waste management and by-product valorization”. In general, the objectives of most studies were focused on identifying environmental hot spots and on comparing different alternative systems. Environmental hot spots mainly concerned the cultivation phase (due to the use of fertilizers, pesticides, and herbicides) and the waste management, while the oil extraction phase was the least variable one. Current trends were addressed to investigate the environmental impacts of the super-intensive olive growing systems and of innovative agricultural practices aimed to increase tree productivity: the mechanized olive harvesting, sustainable control of parasites and weeds, evaluation of different pyrolysis systems of oil mill wastes for energy production, and the valorization of by-products.

It should be noted that even if Scopus is one of the major databases, there are still journals not referenced in Scopus as well as journals not indexed by any other database, and therefore publications in these journals may have been overlooked. Thus, a more comprehensive study might not only consider other databases for scientific papers but also include policy papers and technical reports. Patent datasets could also be explored to better understand the landscape of technological development derived from R&D outputs.

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Appendix A

Table A1. Olive oil production and olive oil consumption per country (means of the years 2017–2021 [130]), and a number of published documents on LCA of olive oil supply chain.

Country	Olive Oil Production		Olive Oil Consumption		Scientific Documents	
	Tons	%	Tons	(%)	N.	%
Spain	1,371,400	44.2	495,120	16.0	20	13.7
Italy	284,960	9.2	471,000	15.2	59	4.1
Greece	255,200	8.2	116,460	3.8	10	6.8
Tunisia	229,000	7.4	33,800	1.1	4	2.7
Turkey	214,900	6.9	163,900	5.3	2	1.4
Morocco	151,000	4.9	134,000	4.3		
Syria	119,400	3.8	100,700	3.2		
Portugal	109,000	3.5	65,340	2.1	3	2.5
Algeria	87,800	2.8	87,300	2.8		
Egypt	36,100	1.2	36,000	1.2		
Argentina	31,400	1.0	7600	0.2		
Jordan	24,200	0.8	23,500	0.8	1	0.7
Palestine	21,700	0.7	15,100	0.5	1	0.7
Chile	20,200	0.7	8000	0.3		
Lebanon	19,900	0.6	15,700	0.5	1	0.7
Australia	18,700	0.6	47,700	1.5	4	2.7
Libya	16,700	0.5	16,800	0.5		
Israel	16,000	0.5	24,000	0.8		
USA	15,800	0.5	354,500	11.4	2	1.4
Albania	11,900	0.4	13,300	0.4		
Iran	8300	0.3	11,300	0.4	5	3.4
China	6200	0.2	50,000	1.6	1	0.7
Cyprus	5220	0.2	6140	0.2	5	3.4
France	4640	0.1	121,280	3.9	6	4.8
Croatia	4020	0.1	7840	0.3		
Saudi Arabia	3000	0.1	34,700	1.1		
Uruguay	1000	0.0	1700	0.1		
Slovenia	580	0.0	2360	0.1		
Montenegro	500	0.0	500	0.0		
Austria			8340	0.3		
Belgium			15,380	0.5	1	0.7
Brazil			86,500	2.8	1	0.7
Bulgaria			3700	0.1		

Table A1. *Cont.*

Country	Olive Oil Production		Olive Oil Consumption		Scientific Documents	
	Tons	%	Tons	(%)	N.	%
Canada			49,700	1.6		
Czech. Rep.			4860	0.2		
Denmark			6000	0.2	2	1.4
Estonia			860	0.0		
Finland			2840	0.1		
Georgia			500	0.0		
Germany			65,260	2.1		
Hungary			2940	0.1		
Iraq			1500	0.0		
Ireland			4280	0.1	2	1.4
Japan			61,500	2.0		
Latvia			1380	0.0		
Lithuania			940	0.0		
Luxembourg			1520	0.0		
Malta			740	0.0		
Mexico			15,700	0.5		
Netherlands			15,660	0.5	4	2.7
Norway			4100	0.1		
Poland			9580	0.3	1	0.7
Romania			4060	0.1	2	1.4
Russia			24,600	0.8		
Slovakia			1880	0.1		
Sweden			10,420	0.3	1	0.7
Switzerland			15,500	0.5	1	0.7
Taiwan			7900	0.3		
United King.			67,825	2.2		
Uzbekistan			500	0.0		
Other countries	15,480	0.5	142,095	4.6	8	5.4
TOTAL WORLD	3,104,200	100.0	3,104,200	100.0		

Table A2. Most active institutions on research on LCA of olive oil production.

Institution	Country	N. of Publications			Total Number of Citations	Average Number of Citations *
		Total	Articles on a Journal	Book Chapter—Conference Paper		
Mediterranean University of Reggio Calabria	Italy	12	11	1	170	14
University of Perugia	Italy	7	7		199	28
University of Bari Aldo Moro	Italy	6	6		420	70
University of Basilicata	Italy	6	4	2	107	18
University of Milano	Italy	6	6		63	11
Frederick University	Cyprus	4	2	2	94	24
University of Toulouse	France	4	4		61	15
INRAE Occitanie-Toulouse	France	4	4		61	15
University of Messina	Italy	4	3	1	188	47
University of Catania	Italy	4	4		29	7
University of Foggia	Italy	4	4		58	15
University of Sassari	Italy	4	4		32	8
University of Jaén	Spain	4	4		11	3

* Number of citations divided by the number of articles.

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