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COLLANA DEL DIPARTIMENTO DI ECONOMIA AZIENDALE

A cura di
MARIA CLAUDIA LUCCHETTI, MARIA FRANCESCA RENZI

QUALITÀ, INNOVAZIONE E SOSTENIBILITÀ NELLA FILIERA AGRO-ALIMENTARE

Il contributo delle Scienze Merceologiche

RomaTrE-Press
2025

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Collana del Dipartimento di Economia Aziendale

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Indice

Wastes and by-products of the olive oil supply chain: state of art of treatment technologies and eco-efficiency assessment tools

Eleonora Recupero
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University of Messina
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Abstract
Due to its high environmental impacts, the agrifood sector is the subject of policy action for promoting environmental sustainability. Among the agrifood sector, olive oil production is one of the most important compartments in which there is an increasing interest in the search for new strategies and technologies toward an ecological transition. This is because the olive oil supply chain generates a huge amount of waste and by-products that can cause several significant environmental impacts, if not properly managed. Despite this, there is a lack of studies in the literature that deal simultaneously with both aspects related to the treatment technologies adopted and the evaluation of their eco-efficiency. Therefore, the present study aims to carry out an exploratory analysis of state of the art regarding the technologies and strategies used in the olive oil supply chain for the treatment of by-products and wastes, as well as the tools applied for assessing their eco-efficiency, through a preliminary bibliometric analysis of the scientific literature. The results allow us to identify the trends related to the strategies employed in the olive oil sector from an environmental sustainability and circular economy point of view.

Keywords: olive oil; by-product; technologies; waste management; eco-efficiency; circular economy.

1 Introduction

Olive oil production from Mediterranean countries accounts for about 95% of the world's entire production (Fondazione Qualivita, Filiera olio DOP IGP, 2020). Among EU Member States, Spain exported 301,400 tonnes of olive oil to non-EU Member States in 2018 (52% of extra-EU exports of olive oil in weight). This makes Spain the largest EU exporter of

olive oil to the rest of the world, followed by Italy (191,000 tonnes, 33%), Portugal (56,000 tonnes, 10%) and Greece (20,600 tonnes, 4%). These four countries accounted for 99% of all extra-EU exports of olive oil in 2018. (Eurostat, 2023). The economic importance of olive oil is highly valued worldwide. The global olive oil production in the world accounted for 3,373,881 tonnes in 2020, of which about 73.1% is produced in Southern Europe, 12.9% in Asia, 12.4% in Africa, 1.2% in Americas, and 0.3% in Oceania, (FaoStat, 2020). Many studies (e.g., Carluccio et al., 2003; Dini et al., 2020; Nunes et al., 2022) highlight the beneficial, anti-inflammatory, and antioxidant properties of the compounds contained in olive oil, even though the composition of the product can change depending on several external factors (cultivars, growing conditions, and extraction processes). Its uniqueness is due to the abundance of fatty acids, but also the occurrence of many bioactive molecules, like hydrophilic phenols, phytosterols, tocopherols, and carotenes that provide several functional properties as well as a long storage time due to their high oxidative stability (Jimenez-Lopez et al., 2020: 2-31). The anticancer properties of olive oil seem correlated with the antioxidant activity of phenolic and polyphenolic compounds that are capable of scavenging free radicals and reactive oxygen species. Antioxidant and anti-atherogenic effects of olive oil polyphenols, like oleuropein and hydroxytyrosol, have been vastly confirmed in the literature (e.g., Edgecombe et al., 2000: 105-109; Frankle, 1976: 2996-3002; Gorzynik-Debicka et al., 2018: 2-13). Despite its beneficial properties, olive oil has several adverse environmental effects (Ncube et al., 2022: 1-21). For example, olive oil extraction generates huge amounts of waste that can have a great impact on the terrestrial and water environment due to their high phytotoxicity. (Paredes et al., 1987: 1557-1564), on aquatic ecosystems (DellaGreca et al., 2001: 352-359) and even in the atmosphere (Rana et al., 2003: 49-58). However, many treatment techniques and technologies have been proposed in the literature; many from the point of view of even just laboratory-scale research (Komnitsas & Zaharaki, 2012, 1-8; Pampuri et al., 2021, 1-23), and others also transposed to industrial scale (Amaral-Silva et al., 2017, 1336-1344; Nieto et al., 2009, 2017-202). Unfortunately, among these studies, few authors highlight aspects of environmental sustainability of these treatment practices, which many times cause the production of other by-products and treatment wastes, that require special attention. For example, different studies evaluate the treatment efficiencies of advanced oxidation systems with the Fenton reaction on olive oil wastewater (e.g., Khoufi et al., 2006, 2007-2016; Mehdaoui et al., 2022, 20450-20468); the Fenton reagent, made up of Fe^{2+} ions and hydrogen peroxide H_2O_2, constitutes a source of OH radicals· with high oxidizing potential but also produces a sludge rich in the catalyst and Fe3+ precipitated by the

reaction which could be recovered but rarely recovered (Domingues et al., 2018, 1-17). In this regard, the ecological transition of the olive supply chain and, in particular, of the related waste treatment technologies is made even more challenging due to the lack of studies that focus on the evaluation of eco-efficiency. Although in literature there is not a common definition of eco-efficiency, the existing ones capture different aspects (Koskela & Vehmas, 2012): i) the first is related to the statement of "more from less", by which eco-efficiency is seen as a solution for producing more physical output from less use of natural resources; ii) the second aspect is related to the "ratio between economic output and environmental output", and the focus is either on productivity (i.e., producing more value-added with less environmental impacts) or on intensity (i.e., decreasing the environmental intensity of the economic performance); and iii) the last which describes eco-efficiency as "*management strategy"* in which the basic idea is that a company simultaneously improves its economic and environmental performance. However, the main aspect is that eco-efficiency may be considered as a ratio between the reduction of environmental impacts and the increment of the value of production (Huppes & Ishikawa, 2005, 2-4). The underlying idea is that by creating "more value with less impact" through eco-efficiency, society can move towards using resources more sustainably (World Business Council for Sustainable Development, 2000) (Figge & Thorpe, 2023, 1-11). In this regard, a potential solution to achieve and increase eco-efficiency may be represented by the application of models and strategies based on the concept of Circular Economy (Figge & Thorpe, 2023, 1-11). According to the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2013a, p. 7), the circular economy represents "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models. In other words, the circular economy, is an alternative pathway to eco-efficiency, although scholars often, combine this with operational eco-efficiency (Bocken et al., 2016: 308-320; Geissdoerfer et al., 2020: 1-18). In this way, at least in theory, eco-efficiency and circular economy may be complementary, with the common goal of reducing resource use overall through technological innovation.

This study aims to carry out a bibliometric analysis of the scientific literature aimed at preliminarily exploring the state-of-the-art of waste and by-product treatment technologies in the olive oil production processes, also focusing on their valorisation strategies and on how eco-efficiency has been explored in this area. The results are also evaluated from a circular

economy and environmental sustainability perspective, considering the potential synergies resulting from them.

After this introductory section, the structure of the paper is organized as follows:

– methodology section, which presents a detailed description of the literature search method applied.
– results and discussion section, in which the main results of the bibliometric study conducted are highlighted.
– conclusions section, in which the main results of the analysis are summarized, and further future research is proposed.

2 Methodology

The steps of the method pursued were identified through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2014: 1-8). The first step of the method is through the identification of the research question. In particular, to satisfy the aim of this study, two main research questions have been defined: i) what is the state of the art of treatment technologies used for olive oil production by-products and wastes aimed at their valorisation?; and ii) how many of these technologies do the literature associate the concept of eco-efficiency? The literature search has been carried out through Scopus and Web of Sciences (WoS) databases for which two queries, in line with the research questions, have been structured. The research was conducted without defining any specific time frame and was completed in September 2023. In particular, the first query (query 1) was structured as follows: ("olive oil") AND ("by*product*" OR "olive mill" OR "mill waste*") AND ("treatment technolog*" OR "waste* treatment*"); it aims to highlight articles in the literature that deal with by-products and wastes treatment technologies in the olive oil sector. The second query (query 2) was structured as follows: ("olive oil") AND ("by*product*" OR "olive mill" OR "mill waste*") AND ("eco*efficienc*" OR "environmental impact*" OR "resource management" OR "environmental sustainability"). Query 2 aims to investigate aspects related to the eco-efficiency concepts in the context of waste and by-products produced in the olive supply chain.

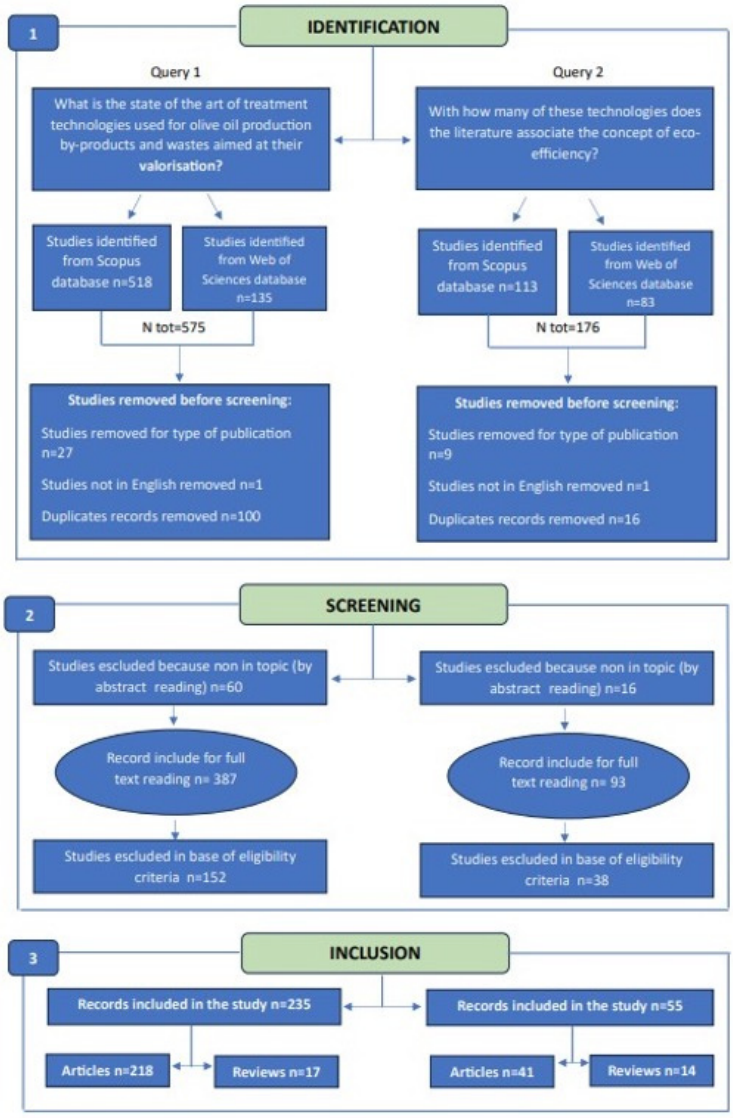

Figure 1 – Search strategy based on PRISMA protocol

As reported in Figure 1, the samples initially identified were n=575 for query 1 and n=176 for query 2. After duplicate removal, the first screening was conducted using databases' filters: a) selected language=English; b) selected document types=articles and reviews. Next, the second screening

was conducted through abstract reading to select only those articles that were directly related to the investigated topics. Finally, the third screening stage involved more specific eligibility criteria to be investigated through full-text reading:

- vfor query 1, only studies in which olive oil by-product and waste treatment technologies and their valorisation were investigated.
- for query 2, only studies in which the assessment of eco-efficiency in the olive oil production sector was proposed, and whether environmental sustainability and circular economy strategies were presented, if any.

Following the sample design phase, n=235 final articles for the first query and n=55 final articles for the second query were identified. Finally, bibliometric data were collected and analysed on Excel workbooks and VOSviewer. In particular, bibliometric analysis is useful for deciphering and mapping the cumulative scientific knowledge and well-established fields by making sense of large volumes of unstructured data in rigorous ways. The aim of the bibliometric analysis is thus to summarise these large quantities of bibliometric data to present the state of the intellectual structure and emerging trends of a research topic (Donthu et al., 2021, 1-12). In this paper for both queries, the bibliometric analysis has been carried out focusing on the annual evolution of publications, the journals in which the selected articles are published, the most cited authors, and the geographical areas of the authors' respective affiliations. In addition, the main subject's areas of the journals, as well as the author's keywords were evaluated through a network analysis. The network metrics of bibliometric analysis allow highlighting the interaction and links between research constituents (e.g., author's keywords, subject areas, affiliations, countries, etc), which may not necessarily be reflected through publications or citations only (Donthu et al., 2021, 1-12). The network analysis has been performed using the VOSviewer software, a freely available computer program that was developed for constructing and viewing bibliometric maps. The functionality of VOSviewer is especially useful for a graphical representation of large bibliometric maps in an easy-to-interpret way (Van Eck & Waltman, 2010, 1-16).

3 Results and Discussion

In this section results and discussion related to the bibliometric analysis of the samples obtained from query 1 and query 2 are reported focusing on years of publication, citations, journals of publication, subject areas, geographical area, and keywords.

3.1 Years of Publication

As shown in Figure 2 which reports the years of publication of the samples, it can be observed that only after the year 2003 there been an increasing interest by the scientific community in analysing the treatment technologies of waste and by-products of olive oil production to achieve their convenient valorisation. Certainly, European environmental policies, that have found fulfillment in the European Green Deal (European Parliament- actuality section, 2020), have greatly influenced the interest of the scientific community in this regard. At the same time, the studies conducted on the eco-efficiency of these treatment technologies, even if slowly and only recently, are also registering an increasing interest in the scientific community.

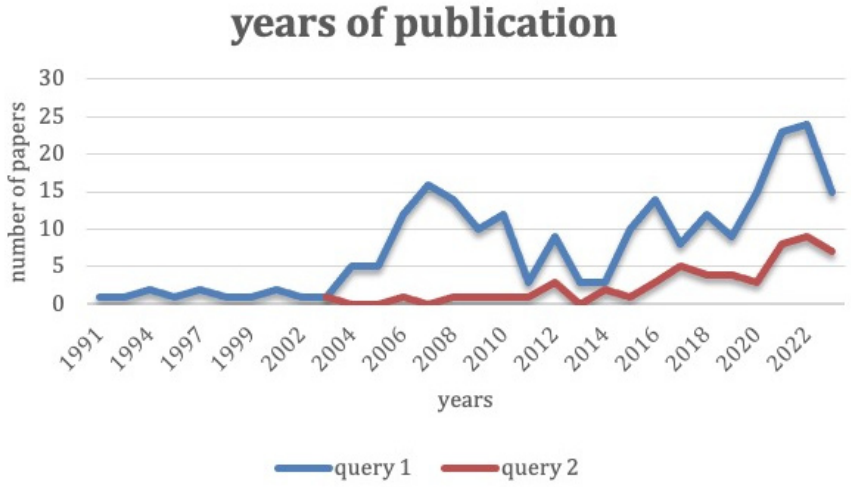

Figure 2 – Publication years of the articles contained in the samples of query 1 and query 2

3.2 Citations of articles

The results of the most cited articles in the two respective samples under analysis are shown in Figures 3 and 4. For simplicity, given the large number of articles in the samples, the analysis is focused on articles having a citation index greater than 100 in query 1, and on articles having a citation index greater than 50 in query 2.

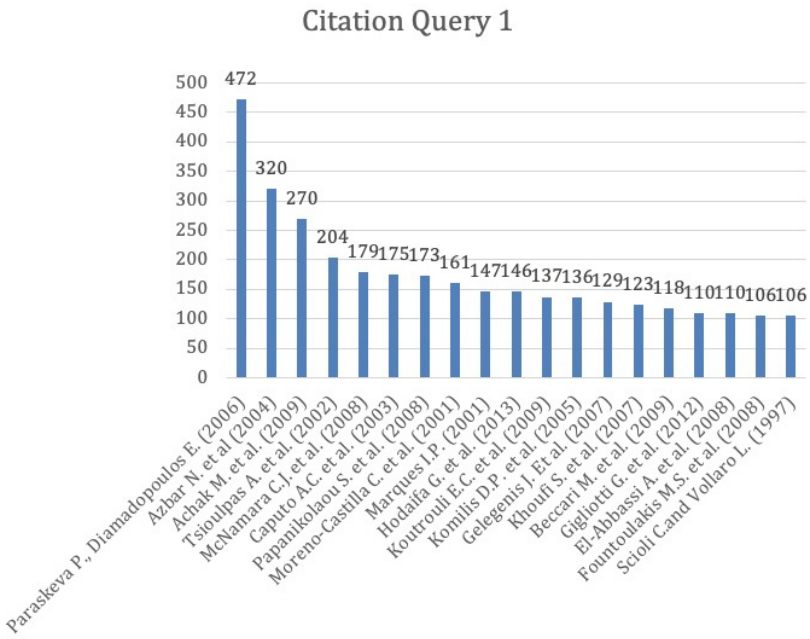

Figure 3 – Number of citations of articles having a citation index greater than 100 in query 1

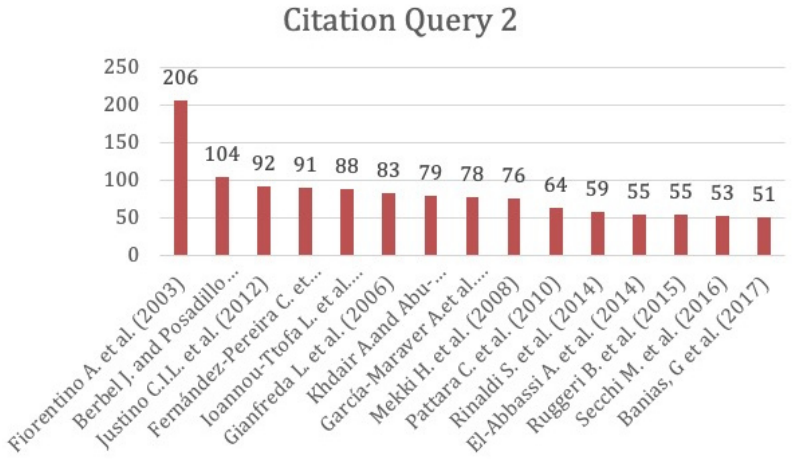

Figure 4 – Number of citations of articles having a citation index greater than 50 in query 2

The most cited article in the research query on olive oil by-product treatment technologies is that of Paraskeva and Diamadopoulos (2006). The authors proposed a comprehensive review expressing the advantages, disadvantages, and abatement yields (of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids) of olive oil mill wastewater treatment technologies distinguish them by chemical-physical treatments and a combination thereof (biological treatments, oxidation and advanced oxidation processes (AOPs), combined processes, composting). The second most cited one belongs to Azbar et al. (2004), who proposed a review to identify the best management systems for solid wastes, consisting of olive pulp, and pits left over after pressing the fruits, as well as for liquid wastes, consisting of vegetable and additional water, produced by the traditional system, two-stage extraction system, and three-stage extraction system. In particular, the authors focused the analysis on waste valorisation through energy recovery from olive stones, treatment of wastewater to be used for fertigation, and sludge composting or animal fodder manufacturing. Both articles turned out to be excellent reference points for a comprehensive overview of olive oil production, its production of waste and by-products, and suitable and known technologies for their treatment from a chemical-physical-biological point of view and respective valorisation or recovery (energy or biomass). On the other hand, the study proposed by Fiorentino et al. (2003) is the most cited article in query 2. The objective of the study was to determine the toxicity of the whole olive oil mill wastewater (OMW) matrix and its different fractions obtained by microfiltration (MF), ultrafiltration, nanofiltration, and reverse osmosis to test the toxicity on aquatic organisms from different trophic levels. The second most cited article in query 2 (Berbel & Posadillo, 2018: 1-9) is a further review of the valorisation of olive by-products (olive pomace, leaves, stone, and olive tree pruning biomass) within the context of bioeconomy[1] strategy, trying to give more weight to the higher levels of the bioeconomy pyramid, e.g., the use of these by-products for animal feed that can be improved by reducing the content of saturated fatty acids (SFA) and increasing the amount of polyunsaturated fatty acids considered beneficial in response to their use. The authors also pointed out that this strategy makes the food healthier for humans and simultaneously reduces the feeding costs and environmental impact of livestock.

The results here permit to highlight how the scientific community

[1] The bioeconomy, often referred to as 'biobased economy', encompasses the production of biobased resources and their conversion into food, feed, bioenergy and biobased materials. A biobased value chain includes the primary production of biobased resources, their conversion to higher-value goods via processing and commercialisation on the market.(Lewandowski, 2018, 1-358).

has given greater resonance to exhaustive studies and reviews containing important insights for further research about olive oil by-products/waste management and valorisation from an environmental sustainability perspective.

3.3 Journals of publication and subject area

The analysis of journals showed that 7% of the sample in query 1 is published in Bioresource Technology, 6% in Waste Management, and 5% in the Journal of Environmental Management, as can be seen in Figure 5**.** The major journals that have emerged are well known for their attention to the discussion of information on solid waste generation, characterization, minimization, collection, separation, treatment, and disposal, as well as manuscripts that address waste management policy, education, and economic and environmental assessments.

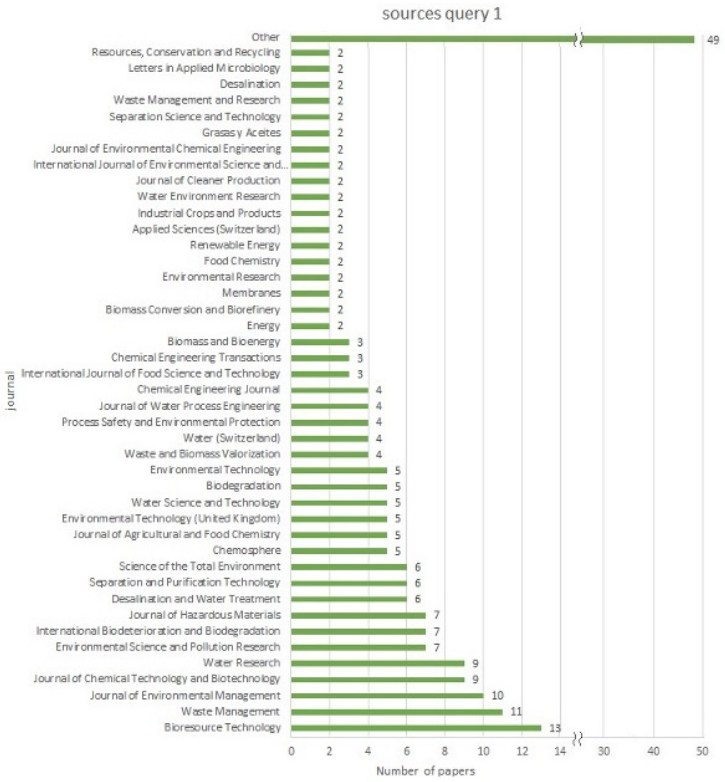

Figure 5 – Waterfall graph representation of the main journals found in query 1 (all journals having only one publication are included in "other")

For the sample obtained from query 2, 8% was published by the Journal of Cleaner Production, and 5% by Science of the Total Environment and Sustainability (Switzerland) (figure 6). It is immediately observed that the main journals in Figure 5 are associated with journals whose goals are environmental protection, resource recovery from waste, and clean production.

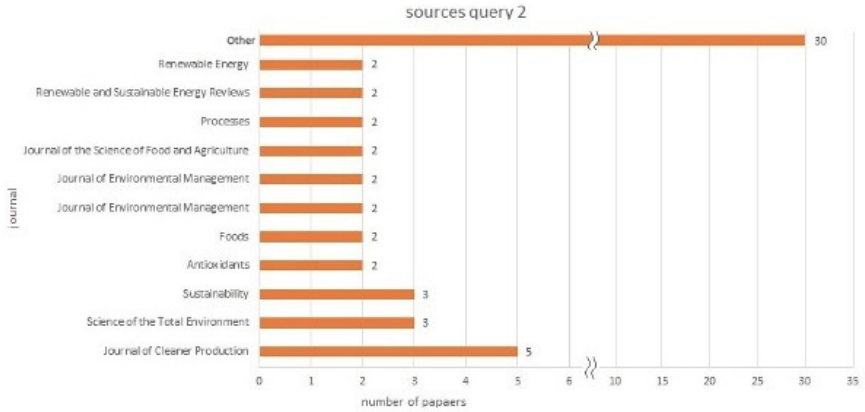

Figure 6 – Waterfall chart representation of the main journals found in query 2 (all journals having only one publication are included in "other")

The analysis of the subject's areas of the most cited journals in query 1 is reported in Figure 7. The main subject areas are Physical Sciences, Environmental Science, and Chemical Engineering, in line with the research topic, which is focused on treatment technologies and management systems for waste and by-product valorisation. However, very interesting is the yellow cluster showing the correlation between Environmental Sciences, Social Sciences, Economics, Econometrics, and Finance, confirming that sustainability is touched on all three dimensions, although the environmental one is more frequent. The green cluster highlights the correlation between Chemistry, Life Sciences, Agricultural and Biological Sciences and Biochemistry confirming the fact that many valorisation systems are related to reuse in agriculture and chemical characterization of biomass, as well as to studies of toxicology and reuse of valuable substances (e.g., antioxidants to be used in drugs formulation). Also interesting are the correlations of Physical Sciences and Environmental Sciences with Medicine, Energy, and Health Sciences, which are included in the blue cluster, and are mainly related to the goals of valorisation (energy and therapeutic).

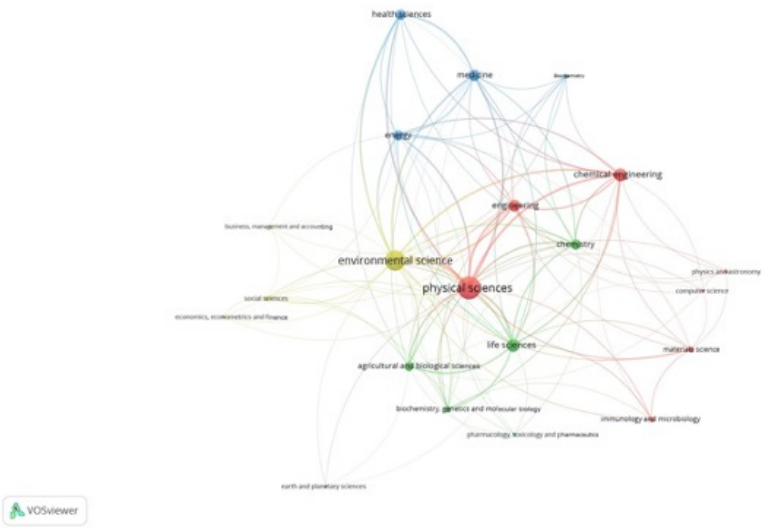

Figure 7 – Network analysis of the subject's areas related to query 1 (elaboration through VOSviewer software)

Similarly, the correlation between the subject's areas of the main journals in query 2 is observed, which again sees the subject's areas of Physical Sciences and Environmental Sciences as the main ones but Social Sciences and Life Sciences are also bordered by these, confirming that in this second research the topics are not only focused on environmental sustainability, but also the on social sustainability (figure 8). Economic, Econometrics Finance fall in the same cluster as Environmental Sciences and Social Sciences but are less frequent in the sample.

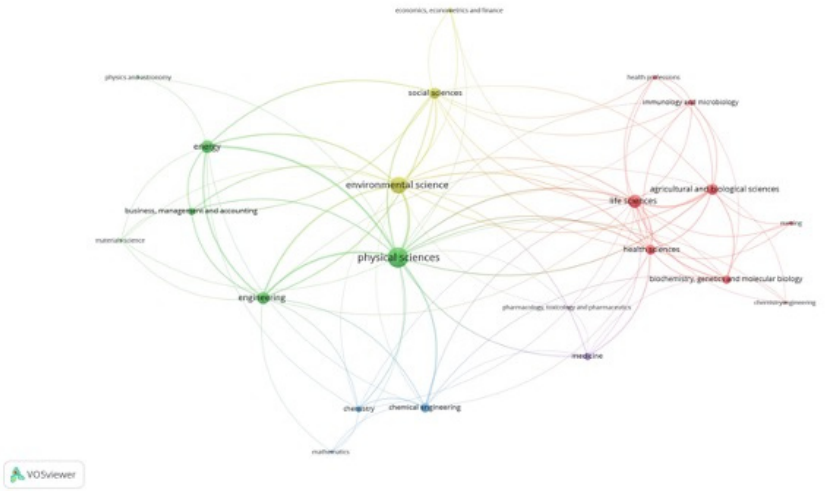

Figure 8 – A network analysis of the subject's areas of the first search (related to query 2 (elaboration through VOSviewer software)

Similarly, we observe that Physical Sciences is included in the cluster of Engineering and Energy confirming the fact that the main trim of mill waste treatment technologies is mainly associated with energy return and the system of engineering strategies and technologies useful for energy enhancement, as suggested by the label of "Engineering" side by side with "Energy". The red cluster with Life Sciences as the main subject areas also includes Health Sciences, Agricultural and Biological Sciences, and Biochemistry, Genetics, and Molecular Biology confirming that the main topics related to sustainability and efficiency include health and biochemical and biological research to improve human health.

3.4 Geographical areas

The analysis of the countries related to the authors' affiliation (figure 9) shows that trends related to geographical area are in line with the world's leading producers of olive oil, represented by Mediterranean countries. Indeed, for query 1 the results point out that Spain is the most representative country (21% of the total sample of articles), followed by Italy with 16%, and Greece with 12%.

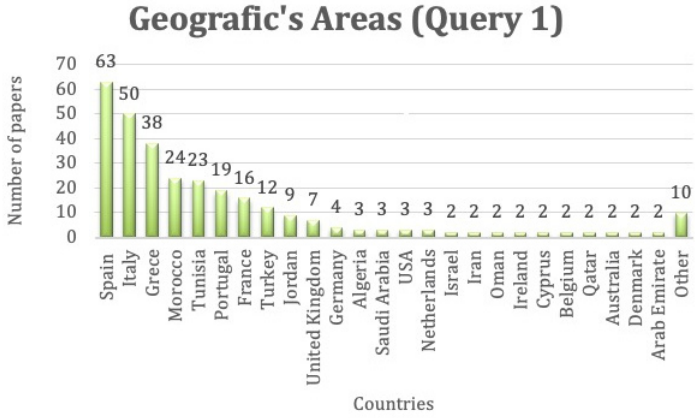

Figure 9 – Distribution of geographical areas related to authors' affiliations for query 1 (all geographic areas with a frequency of 1 are included in "other")

On the other hand, for query 2, results highlight that Italy is the most recurring country (30%), followed by Spain (17%), and Portugal (7%) (figure 10). This also provides an overview of which countries may be mainly focused on the concept of eco-efficiency in the context of the olive oil sector, also investigating the most suitable technologies and tools to increase their sustainability and to achieve the circular economy principles. In this context, Italy is keeping up very well on the circular economy front as well as on the waste management criteria in the olive sector (European Commission, 2022).

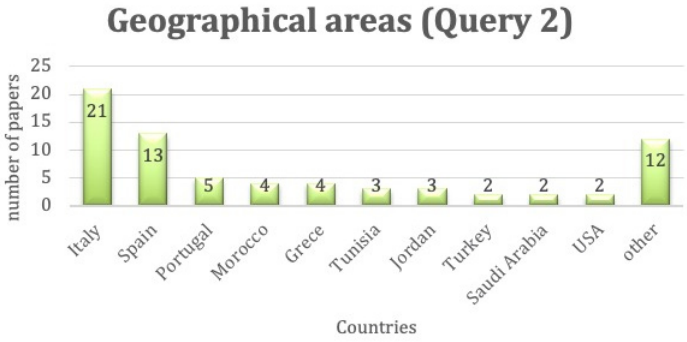

Figure 10 – Distribution of geographical areas related to authors' affiliations for query 2 (all geographic areas with a frequency of 1 are included in "other")

3.5 Author keywords analysis

The results related to the authors' keywords, obtained through a network analysis, allowed the identification of the main areas of investigation related to the research's object as well as the selection of the main paths on these issues, by the scientific community. Regarding query 1, as reported in Figure 11, it can be observed that the most adopted keywords are represented by "olive oil mill waste", "olive mill wastewaters", "physical-chemical treatment", "value-added compound", and "anaerobic digestion".

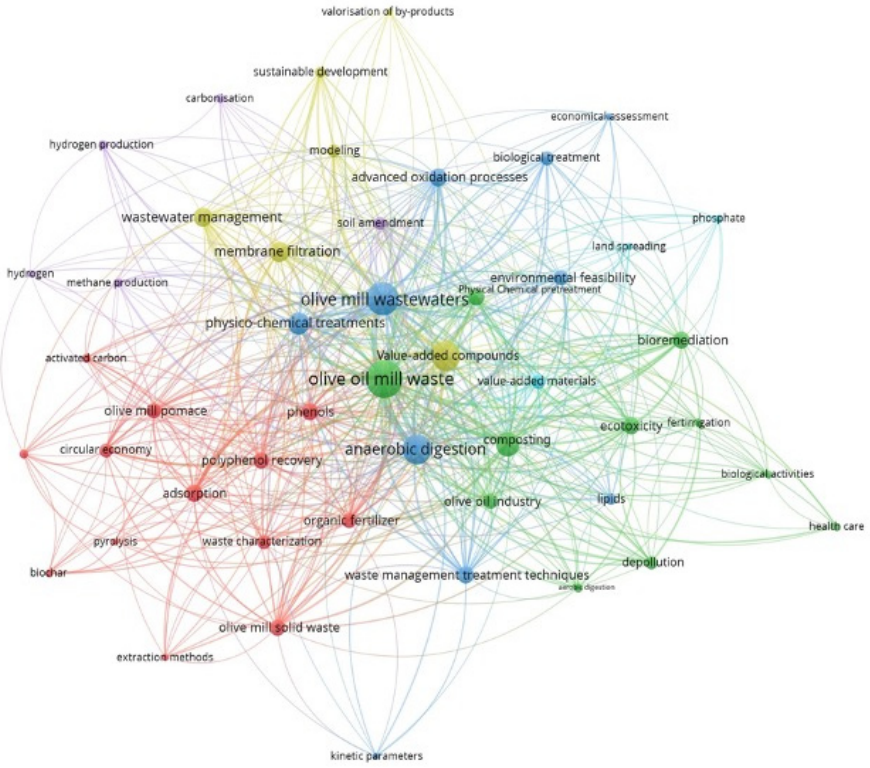

Figure 11 – Visual network mapping representation of VOSviewer related to the authors' keywords for query 1

Olive mill wastes and their treatment technologies are the main topic of the investigated articles; in particular, the main focus of the studies is on OMW and its treatment system. This is because the OMW is obtained in larger quantities by the olive oil production chain (Berbel &

Posadillo, 2018, 1-9) and there are many studies focused on studying the environmental impacts associated with its improper disposal (Koutsos et al., 2018: 942-953). The main treatment technologies for mill by-products and wastes are anaerobic digestion (Donner et al., 2022), chemical-physical treatments (including sedimentation, flocculation/agglomeration, centrifugation, electrocoagulation, and electrochemical treatments), advanced oxidation processes, adsorption, membrane filtration, and composting. While from a point of view, the main by-product valorisation routes are observed: recovery of high value-added compounds, recovery of polyphenolic substances to be used in the production of cosmetics or the pharmaceutical industry, production of activated carbon and energy recovery, compost, fertilizers, soil conditioners, fertigation or also in the building construction industry as substances to improve the quality and strength of materials. Table 1 highlights some examples of the most commonly encountered valorisation technologies in the analysis of query 1, with their respective references.

Reference	Article title	Valorisation systems
(Azbar et al., 2008) (Caputo et al., 2003)	"Enhancement of biogas production from olive mill effluent (OME) by co-digestion"; "Disposal of by-products in the olive oil industry: waste-to-energy solutions"	Energy recovery through biogas production from anaerobic treatments of crusher waste, especially OMW
(Alburquerque et al., 2006) (Galliou et al., 2018)	"Composting of a solid olive-mill by-product ("alperujo") and the potential of the resulting compost for cultivating pepper under commercial conditions". "Production of organic fertilizer from olive mill wastewater by combining solar greenhouse drying and composting"	Processing of olive mill waste into fertilizer, soil conditioner compost, and other agricultural uses
(Carrara et al., 2021) - (Nunes et al., 2022):	"Potential of Olive Oil Mill Wastewater as a Source of Polyphenols for the Treatment of Skin Disorders: A Review" "Potential therapeutic of olive oil industry by-products in skin health: a review"	Recovery of phenols polyphenols and other useful compounds in the cosmetics industry

(Sicari et al., 2023)	"Comparison of Physicochemical Characteristics and Bioactivity of Olive Oil Mill Wastewaters from Traditional and Water-Saving ARA-Controlled Three-Phase Decanter"	Recovery of phenols polyphenols and other compounds useful for their therapeutic action in the pharmaceutical industry
(Barbera, 2020) (Sar et al., 2020)	"Reuse of Food Waste and Wastewater as a Source of Polyphenolic Compounds to Use as Food Additives" "New Insights on Protein Recovery from Olive Oil Mill Wastewater through Bioconversion with Edible Filamentous Fungi"	Recovery of phenols polyphenols and other useful compounds to add them as additives in foods to improve their quality
(Khwaldia et al., 2022)	"Olive byproducts and their bioactive compounds as a valuable source for food packaging applications"	Recovery of useful compounds for the production of bioplastics used in food packaging
(Fernández-Pereira et al., 2011) (Mekki et al., 2008)	"Application of biomass gasification fly ash for brick manufacturing" "Valorization of olive mill wastewater by its incorporation in building bricks"	Use of solid and liquid waste to implement the quality and strength of construction materials

Table 1 – Summary of the main technologies applied for the valorisation of by-products and mill waste resulting from the investigated articles in query 1

Also very interesting is the presence of the keywords "value-added compounds" and "value-added materials" which express the weight that many articles gave to the valorisation of by-products through the extraction and reuse of useful compounds, such as phenols and polyphenols mainly, but also many nutritional contents, that are present in the waste. In addition, focusing the attention on the cluster of keywords that are associated with the concept of circular economy and environmental sustainability, the results show that keywords such as "circular economy", "ecotoxicity", "environmental feasibility", and "sustainable development" have emerged and are carriers of strong interest from the scientific community on these concepts and related issues or opportunities. This is an excellent indication of the ecological thrust toward which research is moving for olive mill waste treatment technologies and olive oil production systems. In particular, it is observed that "circular economy" is mainly associated with the cluster of keywords on the recovery of phenolic and polyphenolic compounds (e.g., Bonetti et al., 2016: 73-86; Camacho et al., 2021: 1-17; Cifuentes-Cabezas

et al, 2022:1-15) and to the thermal treatment of solid crusher by-products (i.e., leaves, pruning waste, and fruit stones) that have a high thermal capacity for energy recovery (Rincón et al., 2009: 2566-2573), for the production of activated carbon (Abu-Dalo et al., 2021: 1-19), but also rich in organic matter exploitable as fertilizer (Parati et al., 2011: 160-163; Zorpas & Costa, 2010;7984-7987). "Ecotoxicity", on the other hand, belongs to the cluster of waste reuse processes in agriculture and thus in association with soil. On the contrary, not much consideration is given to ecotoxicity associated with emissions (Blanco et al., 2022: 1-25; Nasini et al., 2016: 70-76) into the atmosphere or aquatic environment (Fiorentino et al., 2003: 1005-1009). While "sustainable development" is included in the clusters associated with by-product valorisation and models used for waste management; therefore, it is treated little from the point of view of technologies that are more sustainable but is mainly observed from the theoretical (modeling) and by-product valorisation point of view.

Figure 12 reports the results related to the network analysis of authors' keywords for query 2, by which the eco-efficiency of treatment technologies for by-products and mill production waste, from the olive oil sector is investigated.

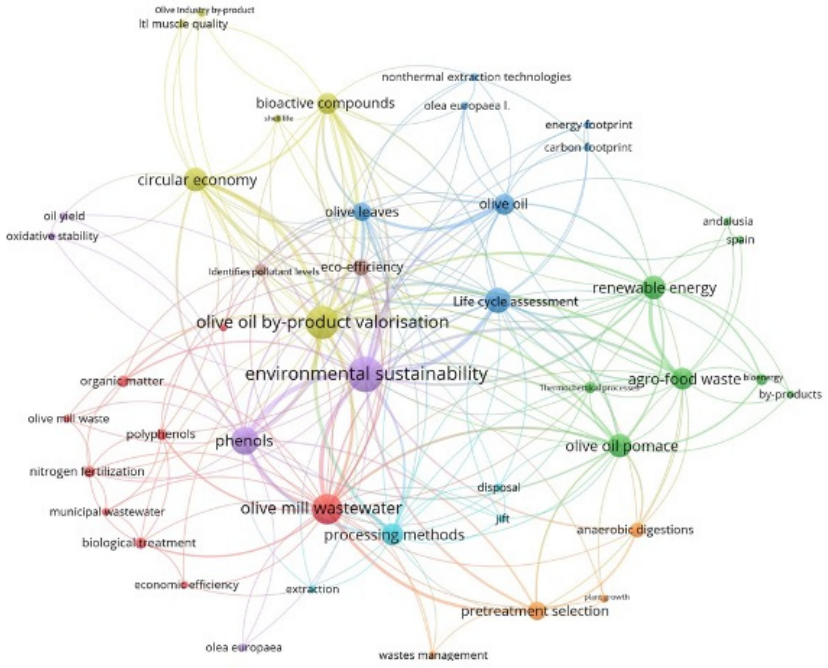

Figure 12 – Visual network mapping representation of VOSviewer related to the authors' keywords for query 2

Through the visual network map, it emerges that the most occurred keywords are represented by "environmental sustainability", "olive oil by-product valorisation", "olive mill wastewater", "circular economy" and "life cycle assessment". Compared to these, less highlighted but still quite frequent is the term "eco-efficiency"; this points out that the authors rarely use the term eco-efficiency to describe the set of studies conducted on resource management in the treatment of olive mill by-products/waste. The focus tends to shift more toward the valorisation processes, circular economy, and the Life Cycle Assessment (LCA). Specifically, the LCA method has been widely adopted by authors to assess the potential environmental impacts associated with all the life cycle stages of olive oil, from raw materials extraction, moving toward agronomic operations, extraction of oil storage, bottling and packaging, distribution, and end-of-life (e.g., Fernández-Lobato et al., 2022: 1-17; Ozturk et al., 2023: 1-9; Ruiz-Carrasco et al., 2023: 1-23). All this fits into the categories of main keywords highlighted above. Thus, in the range of articles selected during the research,

many aspects of environmental sustainability and circular economy were touched by the authors, and the LCA method has emerged as a tool for evaluating eco-efficiency. In fact, the keywords analysis highlighted that the two terms are linked. Also, very often eco-efficiency has been associated, as shown in the study conducted, with the levels of pollutants emitted into the environment (Secchi et al., 2016: 269-281), so surely it is treated in an aspect exclusively related to the environmental externalities caused by these wastes that only partially belongs to the concept of eco-efficiency. From the point of view of by-product valorisation, it is interesting to note the relationship between "olive oil by-product valorisation" and "circular economy" and "bioactive compounds", so the strength of the circular economy aspects expressed in these articles lies in the valorisation of by-products to obtain new products with added value, especially in the area of useful bioactive substances present in the waste. But, the valorisation of by-products also touches in an important way on renewable energy, which is related to the thermochemical processes of treatment of olive pomace and solid olive mill and agrifood waste, that are used as fuel biomass, and the production of energy to be used in the same production system (e.g., Fernández-Lobato, Aguado, et al., 2022: 1-17; García-Maraver et al., 2012: 745-751; Pattara et al., 2010: 1484-1489). The term "life cycle assessment" is certainly central to the research sample. Indeed, several links emerge between "life cycle assessment" and olive oil, environmental sustainability, energy, carbon footprint (Rinaldi et al, 2014), renewable energy use (Parascanu et al., 2018: 586-601), waste valorisation (Blanco et al., 2022: 1-25), circular economy, and eco-efficiency. This confirms that eco-efficiency has not been a topic dealt with as a viable means to affirm the total ecological transition of olive oil production, but it is considered as part of the already well-established model of circular economy and LCA method. At least, from the analysis of the keywords networks the LCA method emerged as the main tool used to evaluate the environmental performances related to the olive oil supply chain, the treatment technologies for the by-products and wastes valorisation, as well as potential circular economy strategies.

4 Conclusions

This study aimed to highlight, through a bibliometric analysis, a preliminary state of the art concerning by-product and waste treatment technologies focusing on their valorisation processes and identify how their eco-efficiency has been investigated, also considering the concept of environmental sustainability and circular economy. Therefore, starting from two main research questions, the study of this paper focused on two

searches conducted simultaneously on Scopus and WoS databases, and for each search, subjected to the same selection process, the trend of publications during the years, the types of associated journals, which were the most cited articles, and the main geographical areas were investigated. Finally, the subject's area and author keywords were also investigated, which overall allowed the identification of the main study topics that emerged among the investigated articles. The results highlighted that the main waste analysed was olive mill wastewater, while the main technologies for treatment and valorisation were anaerobic digestion, initiated mainly with yeasts for the production of biogas, and thus for energy recovery; AOPs that allow high yields of reduction of liquid waste toxicity; nano- and ultra-membrane filtration that allow to obtain biomass from wastewater, which in turn can be recovered; and adsorption with activated carbon or other adsorbents of organic origin for recovery of phenolic matter. Thus, all levels of the bioeconomy pyramid were touched upon with greater weight, however, for the lower levels of material and energy recovery. It was interesting to find at this early stage of the study, the presence of themes related to circular economy, environmental sustainability, and toxicity, expressing reasonable attention to these environmental aspects and related concepts. Furthermore, the main results pointed out that the themes of circular economy, LCA, and by-product valorisation were very present in the sample analysed, and in association with these minimally touched on eco-efficiency. The latter did not emerge as an indicator to accompany the circular economy to direct concrete measures to the ecological transition of this production sector. Therefore, despite eco-efficiency being an important concept, already initiated in studies of agribusiness production for the implementation of the ecological transition, in the olive oil sector and the treatment of its by-products and wastes, it is not particularly well established as such. Only the LCA method has emerged as a tool for evaluating eco-efficiency.

The proposed bibliometric analysis provided a preliminary overview of the main trends and topics related to the subject of study (namely the analysis of the state-of-the-art waste and by-product treatment technologies in the olive oil production processes, by focusing on their valorisation strategies and how eco-efficiency has been explored in this area from a circular economy and environmental sustainability perspective), further future research should be oriented on carrying out a detailed analysis of the content of the articles, applying, for example, a systematic or content analysis.

Bibliography

Abu-Dalo, M., Abdelnabi, J., Bawab, A.A. (2021). Preparation of activated carbon derived from Jordanian olive cake and functionalized with Cu/Cu2O/CuO for adsorption of phenolic compounds from olive mill wastewater. *Materials,*14(21), 6636.

Alburquerque, J.A., Gonzálvez, J., García, D., Cegarra, J. (2006). Composting of a solid olive-mill by-product ("alperujo") and the potential of the resulting compost for cultivating pepper under commercial conditions. *Waste Management*, *26*(6), 620-626. https://doi.org/10.1016/j.wasman.2005.04.008.

Amaral-Silva, N., Martins, R.C., Nunes, P., Castro-Silva, S., Quinta-Ferreira, R.M. (2017). From a lab test to industrial application: Scale-up of Fenton process for real olive mill wastewater treatment: From a lab test to industrial application. *Journal of Chemical Technology & Biotechnology*, *92*(6), 1336–1344. https://doi.org/10.1002/jctb.5128.

Azbar, N., Keskin, T., Yuruyen, A. (2008). Enhancement of biogas production from olive mill effluent (OME) by co-digestion. *Biomass and Bioenergy*, *32*(12), 1195–1201. https://doi.org/10.1016/j.biombioe.2008.03.002.

Barbera, M. (2020). Reuse of food waste and wastewater as a source of polyphenolic compounds to use as food additives. *Journal of AOAC International, 103*(4), 906-914.

Berbel, J., Posadillo, A. (2018). Review and Analysis of Alternatives for the Valorisation of Agro-Industrial Olive Oil By-Products. *Sustainability*, *10*(1), 237. https://doi.org/10.3390/su10010237.

Bocken, N.M.P., De Pauw, I., Bakker, C., Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124.

Caputo, A.C., Scacchia, F., Pelagagge, P.M. (2003). Disposal of by-products in the olive oil industry: Waste-to-energy solutions. *Applied Thermal Engineering*, *23*(2), 197-214. https://doi.org/10.1016/S1359-4311(02)00173-4.

Blanco, I., De Bellis, L., Luvisi, A. (2022). Bibliometric Mapping of Research on Life Cycle Assessment of Olive Oil Supply Chain. *Sustainability, 14*(7), 3747.

Bonetti A., Venturini S., Ena A., Faraloni C., (2016). Innovative method for recovery and valorization of hydroxytyrosol from olive mill wastewaters. *Water Sci Technol.* 74 (1): 73-86. https://doi.org/10.2166/wst.2016.181.

Camacho M.A.N., García Lopez A., Martinez-Ferez A., Ochando-Pulido J.M. (2021) Two-phase olive-oil washing wastewater treatment plus phenolic fraction recovery by novel ion exchange resins process modelling and optimization. *Separation and Purification Technology*. Volume 269, 15 August 2021, 118755.

Carluccio, M.A., Siculella, L., Ancora, M.A., Massaro, M., Scoditti, E., Storelli, C., Visioli, F., Distante, A., De Caterina, R. (2003). Olive Oil and Red Wine Antioxidant Polyphenols Inhibit Endothelial Activation: Antiatherogenic Properties of Mediterranean Diet Phytochemicals. *Arteriosclerosis, Thrombosis, and Vascular Biology*, *23*(4), 622-629. https://doi.org/10.1161/01.ATV.0000062884.69432.A0.

M. Cifuentes-Cabezas, C.M. Sanchez-Arévalo, J.A. Mendoza-Roca, M.C. Vincent-Vela, S. Álvarez-Blanco, (2022) Recovery of phenolic compounds from olive oil washing wastewater by adsorption/desorption process*, Separation and Purification Technology,* Volume 298,121562, https://doi.org/10.1016/j.seppur.2022.121562.

Della Greca, M., Monaco, P., Pinto, G., A. Pollio, L. Previtera & F. Temussi. Phytotoxicity of Low-Molecular-Weight Phenols from Olive Mill Waste Waters. *Bull. Environ. Contam. Toxicol.* 67, 0352-0359 (2001). https://doi.org/10.1007/s001280132.

Dini, I., Graziani, G., Fedele, F.L., Sicari, A., Vinale, F., Castaldo, L., Ritieni, A. (2020). Effects of Trichoderma Biostimulation on the Phenolic Profile of Extra-Virgin Olive Oil and Olive Oil By-Products. *Antioxidants*, *9*(4), 284. https://doi.org/10.3390/antiox9040284.

Domingues, E., Gomes, J., Quina, M., Quinta-Ferreira, R., Martins, R. (2018). Detoxification of Olive Mill Wastewaters by Fenton's Process. *Catalysts*, *8*(12), 662. https://doi.org/10.3390/catal8120662.

Donner, M., Erraach, Y., López-I-Gelats, F., Manuel-I-Martin, J., Yatribi, T., Radić, I., El Hadad-Gauthier, F. (2022). Circular bioeconomy for olive oil waste and by-product valorisation: Actors' strategies and conditions in the Mediterranean area. *Journal of Environmental Management, 321*, 115836.

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., Lim, W.M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285-296. https://doi.org/10.1016/j.jbusres.2021.04.070.

Edgecombe, S.C., Stretch, G.L., Hayball, P.J. (2000). Oleuropein, an antioxidant polyphenol from olive oil, is poorly absorbed from isolated perfused rat intestine. *The Journal of Nutrition, 130(12*), 2996-3002.

European Commision, Brussels, 8.9.2022. COMMISSION STAFF WORKING DOCUMENT Environmental Implementation Review 2022 Country Report – ITALY.

Fernández-Pereira, C., De La Casa, J.A., Gómez-Barea, A., Arroyo, F., Leiva, C., Luna, Y. (2011). Application of biomass gasification fly ash for brick manufacturing. *Fuel, 90(1),* 220-232.

Fernández-Lobato, L., Aguado, R., Jurado, F., Vera, D. (2022). Biomass gasification as a key technology to reduce the environmental impact of virgin olive oil production: A life cycle assessment approach. *Biomass and Bioenergy, 165,* 106585.

Fernández-Lobato, L., Aguado, R., Jurado, F., Vera, D. (2022). Biomass gasification as a key technology to reduce the environmental impact of virgin olive oil production: A life cycle assessment approach. *Biomass and Bioenergy, 165,* 106585.

Figge, F., Thorpe, A.S. (2023). Circular economy, operational eco-efficiency, and sufficiency. An integrated view. *Ecological Economics*, *204*, 107692. https://doi.org/10.1016/j.ecolecon.2022.107692.

Fiorentino, A., Gentili, A., Isidori, M., Monaco, P., Nardelli, A., Parrella, A., Temussi, F. (2003). Environmental effects caused by olive mill wastewaters: toxicity comparison of low-molecular-weight phenol components. *Journal of Agricultural and Food Chemistry*, 51(4), 1005-1009.

Frankle R.T. (1976) Nutrition education in the medical school curriculum: a proposal for action: a curriculum design. *The American Journal of Clinical Nutrition*, Volume 29, Issue 1, January 1976, Pages 105-109. https://doi.org/10.1093/ajcn/29.1.105Get rights and content.

Galliou, F., Markakis, N., Fountoulakis, M.S., Nikolaidis, N., Manios, T. (2018). Production of organic fertilizer from olive mill wastewater by combining solar greenhouse drying and composting. *Waste Management*, *75*, 305–311. https://doi.org/10.1016/j.wasman.2018.01.020.

MacArthur, E. (2013). Towards the circular economy, economic and business rationale for an accelerated transition. Ellen MacArthur Foundation: Cowes, UK, 1.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J.A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J.J., Devereaux, P.J., Dickersin, K., Egger, M., Ernst, E., Gøtzsche, P.C., Grimshaw, J., Guyatt, G., Higgins, J., Ioannidis, J.P.A., Kleijnen, J., Lang, T., Magrini, N., McNamee, D., Moja, L., Mul-

row, C., Napoli, M., Oxman, A., Pham, B., Rennie, D., Sampson, M., Schulz, K.F., Shekelle, P.G., Tovey, D., Tugwell, P. (2014). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. Rev. Esp. Nutr. Humana y Diet. https://doi.org/10.14306/renhyd.18.3.114.

García-Maraver, A., Zamorano, M., Ramos-Ridao, A., Díaz, L.F. (2012). Analysis of olive grove residual biomass potential for electric and thermal energy generation in Andalusia (Spain). *Renewable and Sustainable Energy Reviews, 16(1),* 745-751.

Geissdoerfer, M., Pieroni, M.P.P., Pigosso, D.C.A., Soufani, K. (2020). Circular business models: A review. *Journal of Cleaner Production*, *277*, 123741. https://doi.org/10.1016/j.jclepro.2020.123741.

Gorzynik-Debicka M., Przychodzen P., Cappello F., Kuban-Jankowska A., Marino Gammazza A., Knap N., Wozniak M., Gorska-Ponikowska M. (2018). *Int. J. Mol. Sci. 2018, 19, 547; doi:10.3390/ijms19030686*.

Huppes, G., Ishikawa, M. (2005). Eco-efficiency and Its xsTerminology. *Journal of Industrial Ecology*, *9*(4), 43–46. https://doi.org/10.1162/108819805775247891.

Jimenez-Lopez C., Carpena M., Lourenço-Lopes C.M., Gallardo-Gomez J.M., Lorenzo F., Barba J., Prieto M.A. and Simal-Gandara J. (2020). Bioactive Compounds and Quality of Extra Virgin Olive Oil. *Foods* 2020, 9, 1014; doi:10.3390/foods9081014.

Khoufi, S., Aloui, F., Sayadi, S. (2006). Treatment of olive oil mill wastewater by combined process electro-Fenton reaction and anaerobic digestion. *Water Research*, *40*(10), 2007–2016. https://doi.org/10.1016/j.watres.2006.03.023.

Komnitsas, K., Zaharaki, D. (2012). Pre-treatment of olive mill wastewaters at laboratory and mill scale and subsequent use in agriculture: Legislative framework and proposed soil quality indicators. *Resources, Conservation and Recycling*, *69*, 82-89. https://doi.org/10.1016/j.resconrec.2012.09.009.

Koskela, M., Vehmas, J. (2012). Defining Eco-efficiency: A Case Study on the Finnish Forest Industry: A Case Study on the Finnish Forest Industry. *Business Strategy and the Environment*, *21*(8), 546-566. https://doi.org/10.1002/bse.741.

Koutsos, T.M., Chatzistathis, T., Balampekou, E.I. (2018). A new framework proposal, towards a common EU agricultural policy, with the best sustainable practices for the re-use of olive mill wastewater. *Science of the Total Environment, 622,* 942-953.

Khwaldia, K., Attour, N., Matthes, J., Beck, L., Schmid, M. (2022). Olive byproducts and their bioactive compounds as a valuable source for food packaging applications. *Comprehensive Reviews in Food Science and Food Safety, 21(2)*, 1218-1253.

Lewandowski, I. (2018). Erratum to: Bioeconomy: Shaping the Transition to a Sustainable, Biobased Economy. In I. Lewandowski (A c. Di), *Bioeconomy* (pp. E1-E1). Springer International Publishing. https://doi.org/*10*.1007/978-3-319-68152-8_13.

McIntyre, R.J., Thornton, J.R. (1978). On the environmental efficiency of economic systems. *Soviet Studies*, *30*(2), 173-192. https://doi.org/10.1080/09668137808411179.

Mehdaoui, R., Agren, S., El Haskouri, J., Beyou, E., Lahcini, M., Baouab, M.H.V. (2022). An optimized sono-heterogeneous Fenton degradation of olive oil mill wastewater organic matter by new magnetic glutaraldehyde-crosslinked developed cellulose. *Environmental Science and Pollution Research*, *30*(8), 20450-20468. https://doi.org/10.1007/s11356-022-23276-2.

Mekki, H., Anderson, M., Benzina, M., Ammar, E. (2008). Valorization of olive mill wastewater by its incorporation in building bricks. *Journal of Hazardous Materials, 158(2-3)*, 308-315.

Nasini, L., De Luca, G.D., Ricci, A., Ortolani, F., Caselli, A., Massaccesi, L., Proietti, P. (2016). Gas emissions during olive mill waste composting under static pile conditions. *International Biodeterioration & Biodegradation, 107,* 70-76.

Ncube, A., Fiorentino, G., Panfilo, De Falco M., Ulgiati S. (2022) Circular economy paths in the olive oil industry: a Life Cycle Assessment look into environmental performance and benefits.*Int J Life Cycle Assess.* https://doi.org/10.1007/s11367-022-02031-2.

Nieto, L.M., Hodaifa, G., Vives, S.R., Casares, J.A.G., Driss, S.B., Grueso, R. (2009). Treatment of olive-mill wastewater from a two-phase process by chemical oxidation on an industrial scale. *Water Science and Technology*, *59*(10), 2017-2027. https://doi.org/10.2166/wst.2009.165.

Nunes, A., Marto, J., Gonçalves, L., Martins, A.M., Fraga, C., Ribeiro, H.M. (2022). Potential therapeutic of olive oil industry by-products in skin health: A review. *International Journal of Food Science & Technology*, *57*(1), 173-187. https://doi.org/10.1111/ijfs.15384.

Pampuri, A., Casson, A., Alamprese, C., Di Mattia, C.D., Piscopo, A., Difonzo, G., Giovenzana, V. (2021). Environmental impact of food preparations enriched with phenolic extracts from olive oil mill waste. *Foods, 10(5),* 980.

Parascanu, M.M., Gamero, M.P., Sánchez, P., Soreanu, G., Valverde, J.L., Sanchez-Silva, L. (2018). Life cycle assessment of olive pomace valorisation through pyrolysis. *Renewable Energy, 122,* 589-601.

Paraskeva, P., Diamadopoulos, E. (2006). Technologies for olive mill wastewater (OMW) treatment: a review. *Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology, 81(9),* 1475-1485.

Parati, F., Altieri, R., Esposito, A., Lobianco, A., Pepi, M., Montesi, L., Nair, T. (2011). Validation of thermal composting process using olive mill solid waste for industrial scale cultivation of Agaricus bisporus. *International Biodeterioration & Biodegradation, 65(1)*, 160-163.

Pattara, C., Cappelletti, G.M., Cichelli, A. (2010). Recovery and use of olive stones: commodity, environmental and economic assessment. *Renewable and Sustainable Energy Reviews, 14(5),* 1484-1489.

Rana, G., Rinaldi, M., Introna, M. (2003). Volatilisation of substances after spreading olive oil wastewater on the soil in a Mediterranean environment. *Agriculture, ecosystems & environment, 96(1-3),* 49-58.

Rincón, B., Borja, R., Martín, M.A., Martín, A. (2009). Evaluation of the methanogenic step of a two-stage anaerobic digestion process of acidified olive mill solid residue from a previous hydrolytic–acidogenic step. *Waste management, 29(9),* 2566-2573.

Ruiz-Carrasco, B., Fernández-Lobato, L., López-Sánchez, Y., Vera, D. (2023). Life Cycle Assessment of Olive Oil Production in Turkey, a Territory with an Intensive Production Project. Agriculture, *13*(6), 1192.

Sar, T., Ozturk, M., Taherzadeh, M.J., Ferreira, J.A. (2020). New insights on protein recovery from olive oil mill wastewater through bioconversion with edible filamentous fungi. *Processes, 8(10),* 1210.

Sicari, V., Custureri, I.M.G., Tundis, R., Loizzo, M.R. (2023). Comparison of Physicochemical Characteristics and Bioactivity of Olive Oil Mill Wastewaters from Traditional and Water-Saving ARA-Controlled Three-Phase Decanter: Sustainability*, 15(5)*, 3890.

Secchi M., Castellani V., Collina E., Mirabella N., Sala S. (2016). Assessing eco-innovations in green chemistry: Life Cycle Assessment (LCA) of a cosmetic product with a bio-based ingredient. Assessing eco-innovations in green chemistry: Life Cycle Assessment (LCA) of a cosmetic product with a bio-based ingredient. *Journal of Cleaner Production*.Volume 129, 269-281.

Van Eck, N.J., Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3.

World Business Council for Sustainable Development, 2000. Eco-Efficiency. Creating more value with less impact, WBCSD, Geneva.

Zorpas, A.A., Costa, C.N. (2010). Combination of Fenton oxidation and composting for the treatment of the olive solid residue and the olive mile wastewater from the olive oil industry in Cyprus. *Bioresource Technology, 101(20)*, 7984-7987.