

Article

A Network Analysis for Environmental Assessment in Wine Supply Chain

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Abstract: In the agri-food sector, the Life Cycle Assessment method (LCA) is used to evaluate the environmental impact of a product. Within agri-food products, wine is among the most analysed products, not only for its economic importance but also for the environmental impact of its activity. The paper aims to identify the main trends in the wine sector revolving around environmental evaluation using the LCA method in the academic literature. The aim is to investigate the literature on life cycle assessment analysis of grape and wine production through the systematic grouping of papers into clusters of research. So, the purpose is to discuss the gaps and insights identified by the study in order to aid in the development of a comprehensive state of the art on the topic. Scopus and Web of Science were used to search all articles following a clear and replicable protocol. The results (keywords) were subjected to co-occurrence analysis using VOSviewer, after which the articles were further analysed. Through a bibliographic coupling analysis, the research results were grouped through a network analysis that allowed identifying the research trends on the topic. Three clusters were identified containing the main lines of research on the subject. The results show that nowadays the literature is focusing on concerns related to climate change and consumer awareness on sustainability issues and certifications as well as environmental impacts generated mainly in the production phase in the vineyard. The research results are of interest for future research on LCA analysis in the wine sector in order to contribute to the discussion on the current model in the global wine sector.

Keywords: wine sector; sustainability; environmental impact; LCA; network analysis; review



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1. Introduction

Environmental sustainability in agricultural production is one of the main and debated areas of discussion in the academic literature [1,2]. Among agri-food products, wine is among the most analysed products, not only for its economic importance [3] but also for the environmental impact of its activity. The wine supply chain can be described through different phases, from the cultivation of the vine and grape production, to the transformation of the product during winemaking, transport and distribution, up to the production of by-products and waste, relevant in a circular economy perspective [4].

Given the importance of viticulture in the characterization of the territory in which it is practiced, the question is of great importance and needs further investigation. From the point of view of the multifunctionality of agriculture, it is necessary to evaluate the ecosystem function of the vineyard and not only the merely productive and therefore economic function. In this context, an economic assessment cannot be distinguished from an environmental sustainability assessment [1,2]. The main gaps in the research on wine

industries relate to the environmental problems of wineries that are still unexplored and little debated in the literature [5].

Consumers are showing increasing interest in environmental sustainability issues, which plays an important role in the choices of agri-food products [6–8]. To respond to the increased attention to the increase in greenhouse gases and issues related to climate change, producers have undertaken new business choices oriented towards sustainable practices both in the cultivation of vines and in the production of wine [9]. At the same time, actions aimed at the correct management of production inputs are growing in the scientific literature [10,11], which increasingly uses environmental assessment through environmental assessment methods, such as Life Cycle Assessment (LCA) [12–14].

The scientific literature on the adoption of LCA in the agri-food sector has shown an unequivocal environmental hotspot in the agricultural phase [2]. The agricultural phase involves the adoption of different agronomic techniques, such as soil management, fertilization, weeding, irrigation, pruning and harvesting [15–20], which require a wide use of inputs such as fuel, fertilization, pesticides and water irrigation [21]. However, the transformation phase of wine production also generates environmental impact due to the packaging materials used [22].

Given the importance of the wine sector, it is important to evaluate the sustainability of this sector and the environmental impacts it generates to ensure that the wine industry is sustainable from an economic but also from an environmental dimension [5,23].

Tools such as the LCA methodology are becoming increasingly important to be able to carry out an environmental assessment of a product or process [1,24–26], considering either the entire life cycle (from cradle to grave) or only some parts of the cycle [27,28]. This tool is increasingly used by the agri-food industry to respond to the demands of consumers who are increasingly sensitive to issues related to sustainability [29]. The LCA is a tool that allows you to analyse and discuss sustainability issues through a conceptual model, based on the deepening of all the impacts that a product or service generates during its entire life cycle, relating to all the components of sustainability, from the design to the disposal of the product used [30–32]. The LCA methodology is widely used to evaluate environmental criticalities and quantify energy and environmental loads and potential impacts, obtaining useful information to express judgments of convenience on all the phases that make up a process understood as correlated and dependent on each other [21]. In the agri-food sector, this method is increasingly used in academic literature, as shown by the increasing amount of information databases to help with its application [33]. In recent years, the use of LCA is also spreading in the wine industry, and several studies have been carried out on this topic. However, its application in the wine sector is still under development [34,35].

The review of the scientific literature was conducted through a bibliometric network analysis, which combines bibliometric and social network analysis [36,37]. The integration of social network analysis and bibliometric science proves to be a useful approach capable of grasping the multidimensional nature of measuring environmental impacts in the wine sector through the analysis of a large amount of literature data [38]. The use of bibliometric network analysis has been shown to be a useful tool for quantitatively assessing trends and patterns in the scientific literature [38]. Recent literature has used bibliometric network analysis to explore studies on environmental problems, life cycle assessment, ecosystem services and circular economy [39–42]. However, to the best of our knowledge, no studies have yet explored the global scientific literature on environmental assessment in the wine supply chain and the relationships between the different research areas that are important in addressing the problem by adopting an interdisciplinary perspective.

This study aims to explore the global scientific literature on the environmental assessment of the wine supply chain by tracing its evolution and trends by applying network analysis to bibliometric science. The purpose of the study is to provide state-of-the-art research on the subject and to deepen the role of the LCA methodology in the environmental analysis of the wine chain. The article offers a bibliometric network analysis of the literature, with the aim of contributing to a better understanding of the literature on the

analysis of the environmental impacts of grapes and wine production. We performed a bibliographic correspondence analysis by identifying three groups of search lines. Then, we analysed each research cluster and opportunities for new emerging research trends still under development. Our research question focuses on the contents of the scientific literature, with the aim of investigating emerging issues in the field of environmental analysis in the wine sector. The overall goal is to provide evidence-based insights for researchers, policy makers and stakeholders in the wine supply chain interested in the topic of environmental assessment in the context of wine.

The article is organized as follows: The first section deals with the introduction, Section 2 describes the method; Section 3 discusses the findings of the literature review; the discussion of the results is described in Section 4; finally, the concluding observations and limitations of this study are presented in Section 5.

2. Method

2.1. Literature Searching Procedure

The review was conducted to analyse academic literature from scientific databases and to summarize the main trends of environmental assessment in the wine and grape sector. A systematic literature review was carried out based on strict keyword search criteria. The research was carried out in October 2021.

The review was carried out following the Preferred Reporting Items for Systematic Review and meta-Analysis (PRISMA) protocol [2,43,44]. The PRISMA procedure provides a detailed, replicable, scientific and transparent protocol [45]. The research was conducted through the online core collection of Elsevier Scopus and Web of Science databases, which are the main online scientific research databases widely recognized by the scientific community for the collection of reliable and multidisciplinary research. In Figure 1, a flowchart with the selection procedure and exclusion criteria [2,44,46,47] is presented. The thematic research area was identified in the LCA analysis in the wine sector with reference to both the agricultural phase of cultivation of the raw material (grape) and the vinification and transformation process of grapes (wine) (Identification phase). The literature searching procedure was conducted by a combination of keywords in the databases. The keywords “wine” OR “grape” AND “lca” OR “life cycle assessment” OR “life-cycle-assessment” were used. The same search query was used on both databases, and the same criteria to ensure the completeness of the data were chosen. The following string was used: (“wine” OR “grape”) AND (“lca” OR “life cycle assessment” OR “life-cycle assessment”).

In the first phase of Identification (Figure 1), the search for keywords initially produced a total result of 397 records, of which 181 were identified through Scopus and 216 through the Web of Science database. The next phase for the selection of the relevant literature took place through the Screening and Eligibility [2,44,46,47]. In the Screening phase, applying the primary exclusion criteria—in this bibliographic search phase, only academic articles published in indexed journals were included—the selected articles identified by Web of Science and Scopus were reduced from 397 to 359 records. Only articles and reviews were considered for research purposes; 38 records were eliminated in this phase, including Books, Chapters, Proceedings, Editorials and Reports. Subsequently, in the Eligibility phase, the duplicates of the articles that came from both databases were eliminated, and therefore the number of articles for this study was reduced from 359 to 230, thus excluding 129 duplicate records. In order to consider the literature as highly visible within the scientific community, 4 non-English articles were excluded during the subsequent Eligibility phase [2,4,44]. In the last phase of the Included stage, a sample of 226 documents was selected to answer our research question.

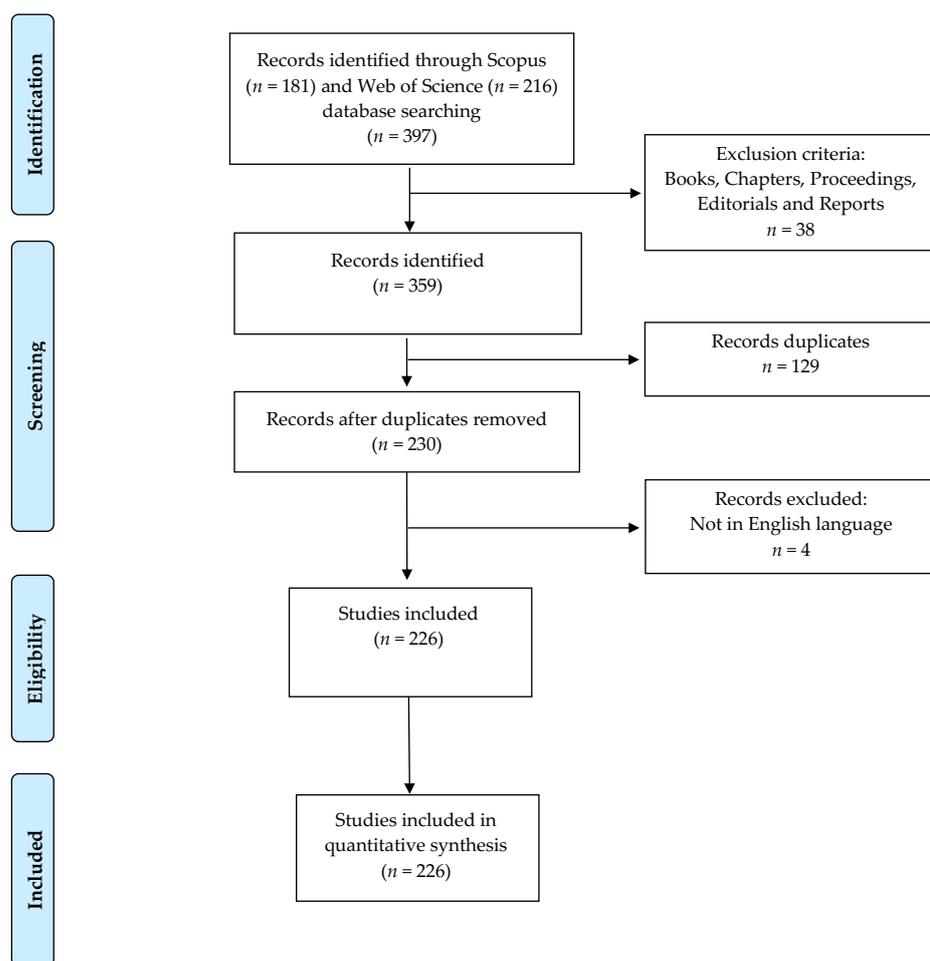


Figure 1. Flowchart diagram in which the selection procedure and exclusion criteria have been identified (PRISMA).

2.2. Bibliographic Analysis of Co-Occurrence Keywords

The results obtained from both scientific research databases were analysed through a co-occurrence analysis method using the VOSviewer software. This JAVA-based software was established in 2010 by Van Eck and Waltman in the Centre for Science and Technology Studies (CSTS) of the University of Leiden as an aid in designing maps created on network data [48]. This tool develops network analyses by elaborating bibliometric maps [49] through a quantitative method, which combines several factors, provide the visual graphical visualization of various forms of data network of scientific publications.

In this phase, keywords, article titles and abstracts (TITLE_ABS_KEY) of the articles previously collected within the scientific databases, and then selected through the PRISMA protocol, were initially loaded into the VOSviewer software. Using the VOSviewer software, maps of the co-occurrence network of the keywords of all the articles selected from the databases under examination were drawn up in the research period available on the databases (1996–2021). VOSviewer is software used to identify and explore bibliometric maps and matches of co-citations and co-occurrence keywords [50,51] and to create distance maps indicating the strength of the relationships between the elements [52]. The software uses two standard weights, such as the number and total strength of the links, to graphically visualize the nodal network [53].

The statistical analysis of keywords using the VOSviewer tool allows to identify the most used and recurring terms in the academic literature and their relationships, from which it is then possible to derive the main research topics relating to the field analysed but also the research topics that are more recent and still under explored, thus allowing assessments

to be made not only of current research but also possible predictions on the themes of possible future trends [54]. The file containing the information of the articles selected for the study was imported into VOSviewer to develop a single network analysis of the three research data above (TITLE_ABS_KEY), based on their relevance and co-occurrence [55]. The “map based on bibliographic data” option was preferred; “co-occurrence” was chosen as the type of analysis; the unit of analysis identified was that of the “keywords”; the counting method preferred was the “full count”; the minimum number of occurrences of a term was 4; and the Number of terms designated was the total number of items, in line with other authors [55,56]. This selection was selected to guarantee higher accuracy in the examination of the results. Several units of analysis can be used in this type of analysis, including journals, publications and authors [48]. The present paper used “publication” as a unit of analysis [57].

3. Results

3.1. Overview of Selected Papers

Information regarding the title, author(s) and year of publication of the selected papers are summarized in Appendix A (Table A1).

The Figure 2 shows the development of academic literature in the period 1996–2021, taking into consideration the number of articles per year. Generally, before 2011, there were fewer than five papers per year. Since 2012, the trend has always been constantly growing.

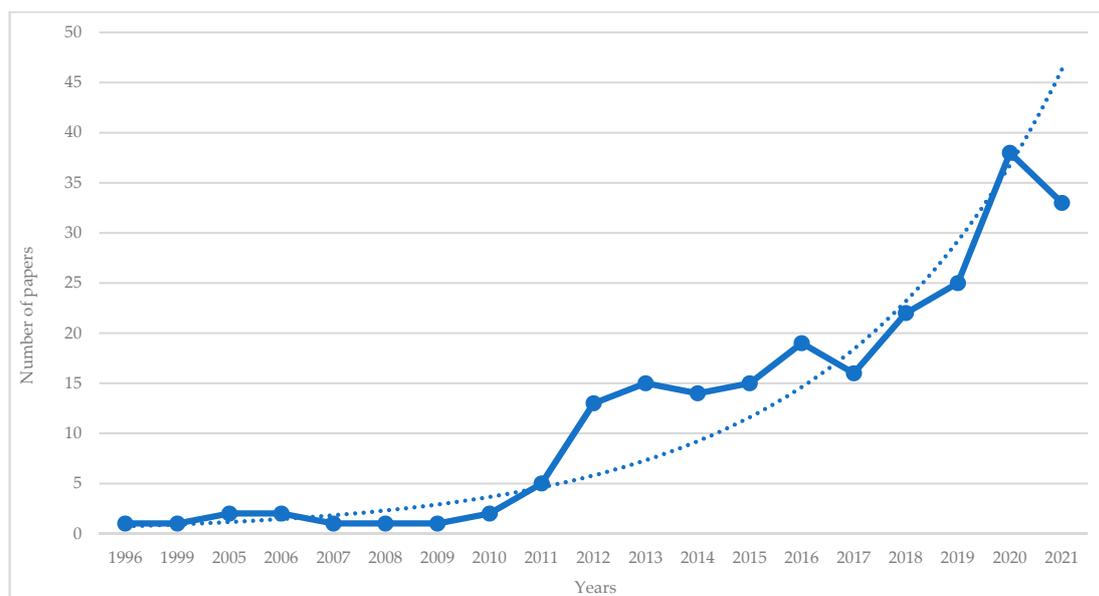


Figure 2. Number of papers per year. (Source: our elaboration).

During the first years, from 1996 to 2009, there was a low interest in these issues, with an average of one publication per year. Despite a general upward trend in the number of publications, there was a decline in the number from 19 to 16 in 2017. The peak has been reached in recent years, especially in 2020, with 38 published papers. This shows that interest in this research has increased.

In Figure 3, journals containing at least two papers are represented. Most of the papers are published in the *Journal of Cleaner Production* with 64 total articles, followed by the *International Journal of Life Cycle Assessment* with 23 articles and *Science of the Total Environment* with 19 articles, *Sustainability* with 15 papers, the *Journal of Environmental Management* (7) and the *Journal of Industrial Ecology* (4). All other journals achieved lower values, as mentioned in Figure 3.

In reference to the nationality of the authors of the studies, most of these are located in Europe, in particular in Italy and Spain, but widespread are authors from North and South

America, Asia, South Africa and Australia. Specifically, Europe is the most productive continent. The country with the largest number of papers is Italy (68), followed by Spain (55), France (24), the United Kingdom (20), the Netherlands (13), Portugal (10), Germany (9), Sweden (8), Peru (8), Greece (6) and Luxembourg (6). These countries compete with Brazil (12), the USA (10), Canada (10), Australia (8) and China (7). The other countries achieved a record of less than five papers (Figure 4).

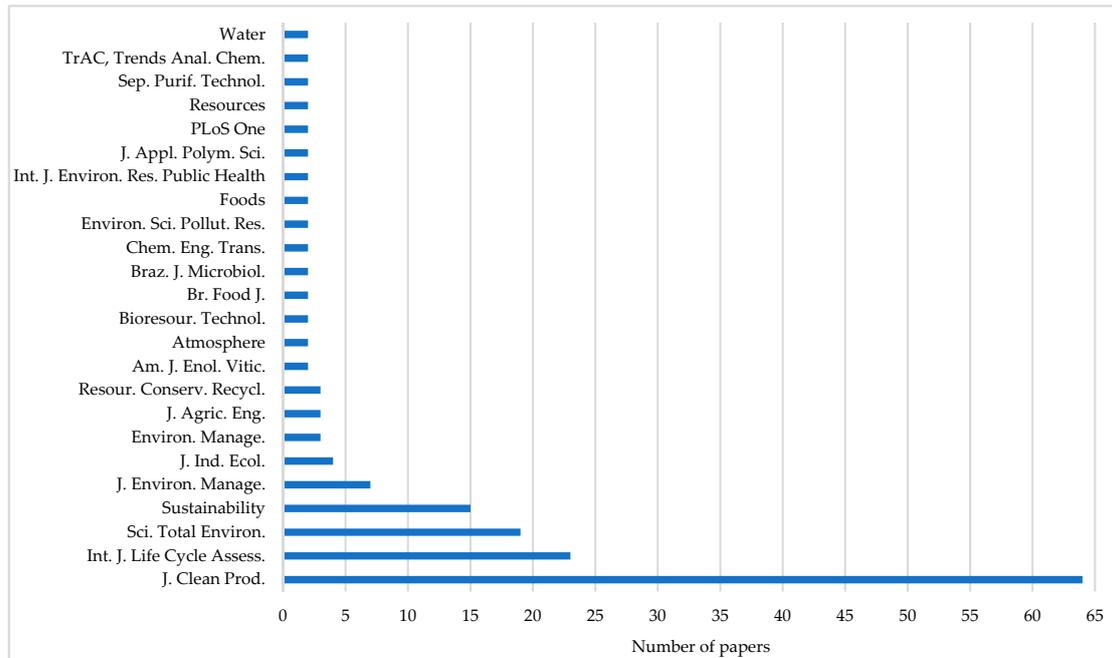


Figure 3. Number of papers per journal. (Source: our elaboration).

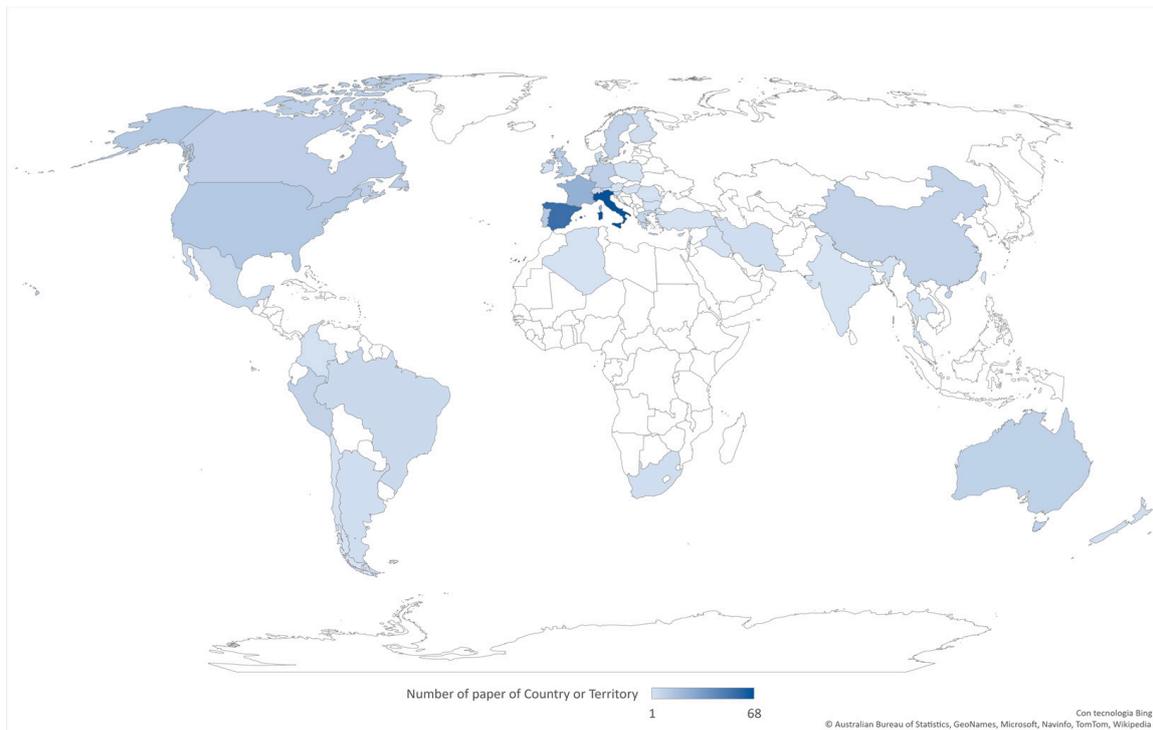


Figure 4. Number of papers published in different countries or territories. (Source: our elaboration).

3.2. Bibliometric Analysis of the Themes

After the selected papers have been collected, VOSviewer software has been adopted to visualize the networks among the data by creating graphical bibliometric maps [58].

The VOSviewer tool provides the essential functionalities to visualize bibliometric networks and co-occurrence links between keywords [50]. VOSviewer is a computer program developed to generate and investigate bibliometric maps [50]. Keywords contained in the article titles and abstracts are explored based on their occurrence to create a map of the occurrences of all terms used in the 226 selected papers. We built a map of the most frequent keywords. We have selected “co-occurrence” as the analysis type, “all keywords” as the unit of analysis, and “four shared keywords” as the minimum level. Then, VOSviewer converted data into a graphic form and categorized frequent keywords into three main clusters in the network view visualization [59]. Larger circles and map labels explain greater importance and meaning. Similarly, colour keywords belong to the same cluster [50] (Figure 5). In the graphic maps, larger circles imply higher relevance for a theme [50]. In Figure 5, red, blue and green colours differentiate the clusters. All three clusters corroborate the research flows obtained from the bibliographic coupling. Nodal outputs based on bibliometric analysis aid to understand the proximity and relevance of keywords and discover possible gaps and insights. The size of the circles represents how often keywords are displayed. The distance between the two circles indicates their correlation.

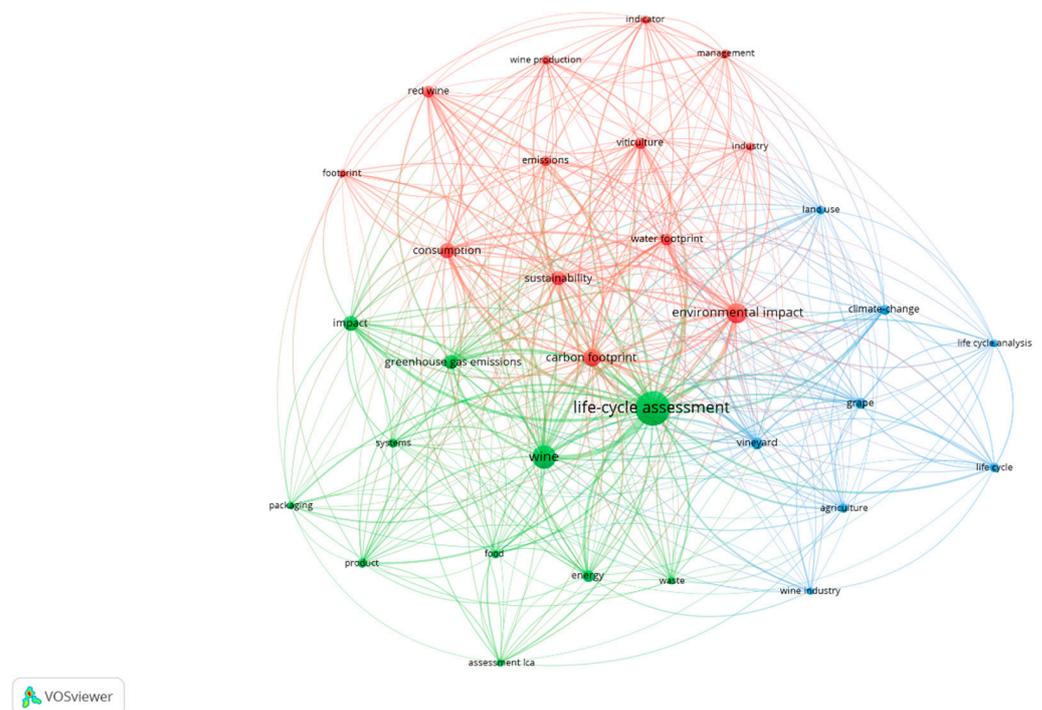


Figure 5. Keyword co-occurrences map. (Source: our elaboration).

In this study, the keywords in the title and abstract of selected papers were included in the final analysis. Three main clusters have been created, which means groups of themes. The first cluster was designated by the red colour and covered 13 elements. The second cluster was expressed by the green colour and involved 11 elements. The third cluster includes 8 elements in blue, as shown in Figure 5.

A keyword cloud was also created to show the frequency and interconnections of keywords that occurred more than four times in the papers selected for this research. “Life cycle assessment”, “environmental impact”, “wine”, “carbon footprint”, “sustainability” and “consumption” and “greenhouse gas emission” seem to be much-studied topics. The strengths of low keywords indicate that more research is needed, as this is still an emerging stage.

It has been indicated that “life-cycle assessment” is also the most frequent keyword (with 190 occurrences), followed by “wine” (with 88 occurrences) and “environmental impact” (with 66 occurrences) and “carbon footprint” (with 51 occurrences). All other keywords scored lower.

The keywords that have appeared the most and with stronger interconnected links are “life-cycle assessment” (total connection strength 633), “environmental impact” (total connection strength 302) and “vineyard” (total connection strength 302), which had a strong link with “carbon footprint” and “wine”.

The literature published on the measurement of the environmental impacts of the wine production chain using LCA methodologies includes the following three aspects: wine industry (red), agricultural phase (blue) and winemaking phase (green). Through the analysis of keywords and the analysis of their recurrence, it was possible to identify three clusters of main research topics (Figure 5).

The (1) first cluster, in red colour, involved documents that study the environmental impacts in the wine industry, referring to sustainability indicators in the sustainable management of the wine industry, as well as the measurement of impacts along the industry and consumer demand for sustainability certifications.

The (2) second cluster, in blue colour, contains articles that investigate the environmental impacts in the agricultural phase, with a particular focus on the vineyard management and, therefore, the analysis of the life cycle delimited to the agricultural phase for the grape production.

The (3) third cluster, in green colour, concerned environmental assessment documents concerning the life cycle analysis in the vinification phase for the wine production, with particular attention to the materials used for packaging but also to the generation of products and waste.

In Figure 6, the temporal evolution over the years of the topics investigated in the literature and the keywords used are reported. The most used keywords starting from the first half of 2016 were “assessment lca”, “life cycle analysis”, “food”, “wine industry” and “emission”. These words indicate that the lines of research in 2016 were mainly dedicated to the literature on the LCA methodology in the wine industry and the consequent measurement of the impacts of this with particular interest in the emissions generated.

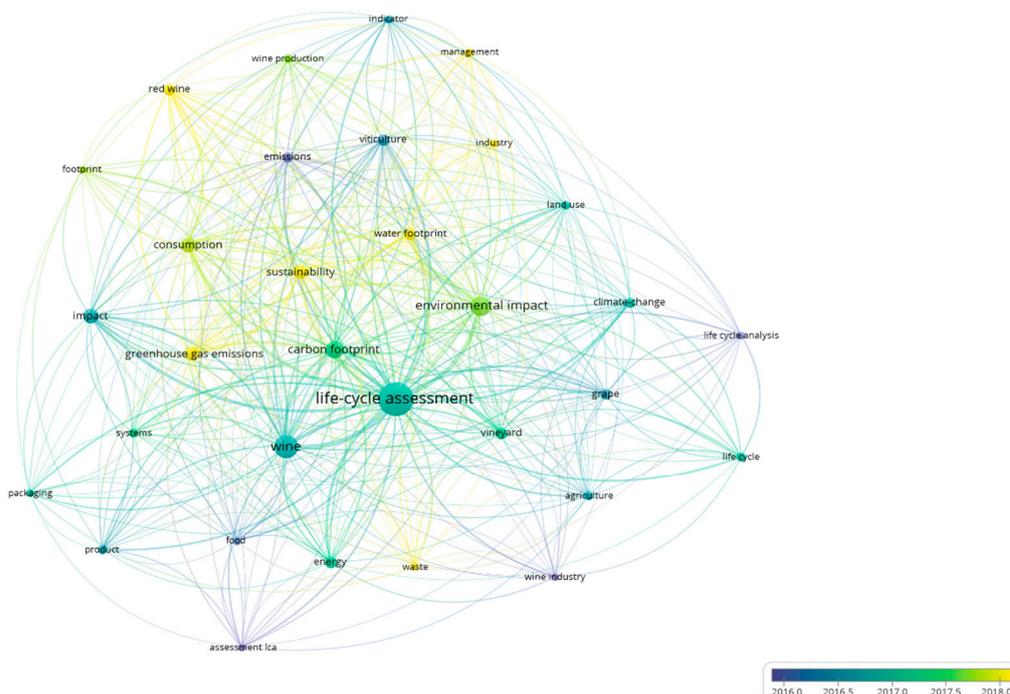


Figure 6. Keyword co-occurrences map per year. (Source: our elaboration).



Figure 8. Number of Item (keyword) per Cluster. (Source: our elaboration).

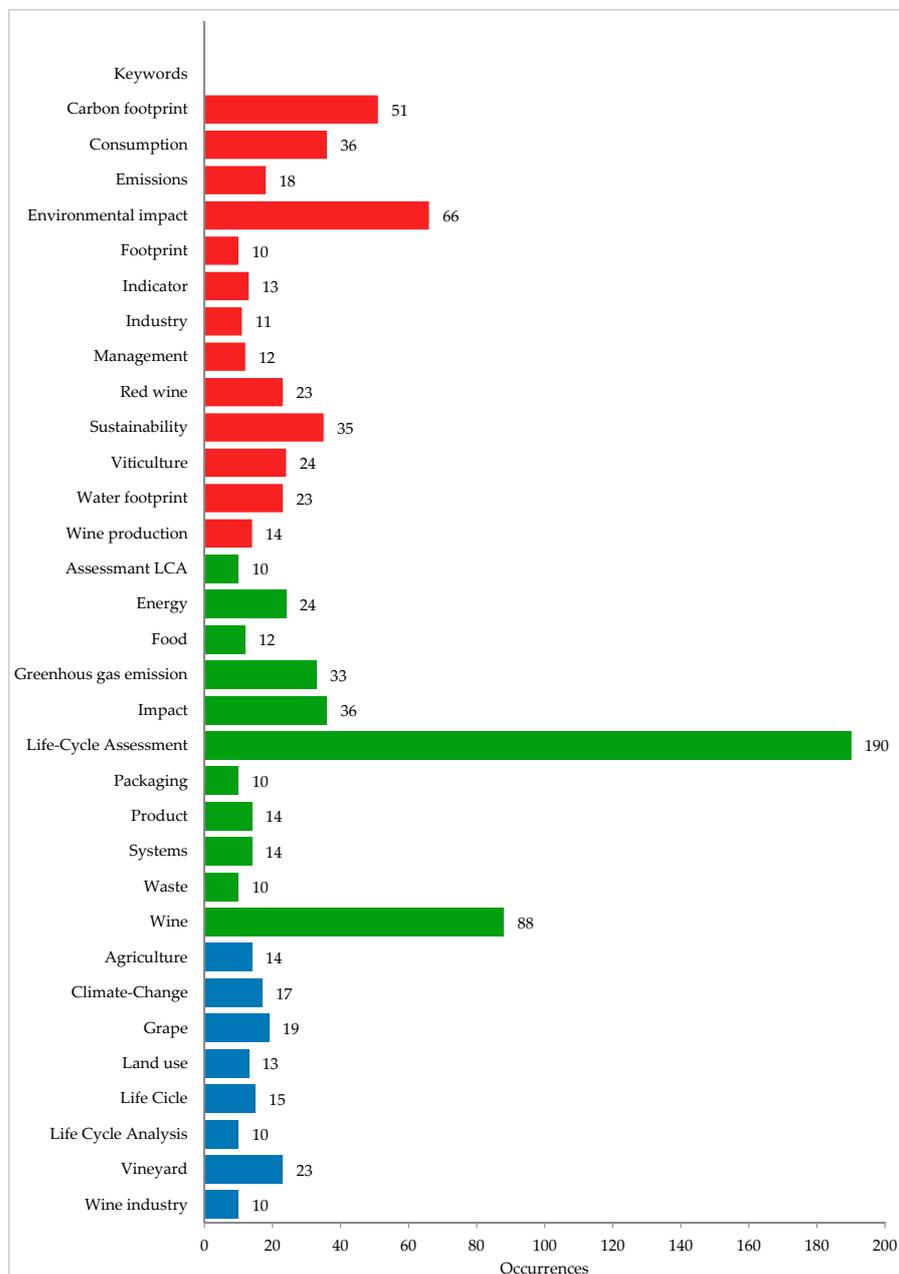


Figure 9. Occurrences keywords. (Source: our elaboration).

Table 1 summarizes the 3 most relevant keywords in this study. The keyword “Life-cycle assessment” is confirmed as the most important word. This belongs to the second cluster (green), with 31 links, 633 total link strength and 190 occurrences. The second most important keyword is “environmental impact” belonging to the first cluster (red), with 31 links, 302 total link strength and 66 occurrences. Finally, the third most important word is “vineyard” belonging to the third cluster (blue) with 28 links, 122 total link strength and 23 occurrences.

Table 1. Representative keywords via network visualization of VOSviewer.

Keywords	Cluster	Colour	Links	Total Link Strength	Occurrences
Environmental impact	1		31	302	66
Life-Cycle Assessment	2		31	633	190
Vineyard	3		28	122	23

4. Discussion

4.1. Overall Comment

Interest in the issues of environmental sustainability is increasingly widespread in the agri-food sector and in particular in the wine sector. In this study, through an analysis of the literature and a bibliometric analysis of the themes, their interconnections and new research topics, it has been possible to deepen the main problems studied and those recently emerging in the academic literature on the theme of the sustainable management of production in viticulture. Among the agri-food products, the wine industry arises as one of the main sectors in which environmental assessment is most used, given its importance from an economic point of view but also for its generation of outputs such as emissions, by-products and waste. The analysis of the bibliometric network provides an overview of the main aspects that characterise the problem of environmental assessment in the wine sector, allowing the investigation of the relationships between keywords. The integration of the analysis of social networks and bibliometric science has led to a useful approach capable of capturing the multidimensional nature of environmental assessment by analysing a large amount of literature data. The maps of the network show that environmental assessment is a complex issue that affects multiple research fields. The keyword map of the co-occurrence network has shown that the main focus of research in recent years has shifted towards greater attention to issues related to climate change and consumer awareness on the issues of sustainability, certifications and related environmental impacts to the agricultural production phase. Through the analysis of the keywords and the analysis of their co-occurrence, it was possible to identify three main clusters of research topics: environmental impacts in the wine industry, the agricultural phase and the winemaking phase.

4.2. Environmental Impact in the Wine Industry

Viticulture, distribution and packaging of wine are the main environmental impacts of the wine industry [60].

The interest of producers is increasingly aimed at reducing the environmental impact of their production through environmental strategies, for example, through ecolabeling [61,62] or eco-design for the supply of novel environmentally friendly products [63].

Today, in the wine sector, the LCA tool is of great interest to producers as it is used for the assessment of environmental loads along all wine production processes, to consent the identification and reduction of hotspots in the life cycle of the wine production and to transmit this information for communication purposes to the consumer [64,65].

The use of an environmental assessment of emissions is indirectly able to favour a more equitable and transparent distribution of the responsibilities of the environmental loads produced in a process amongst the various stakeholders in the wine chain [66,67]. Most of the studies in the literature aim to identify the critical points of the wine life cycle; some authors calculate an extensive detailed choice of LCA impact categories, others are

oriented towards the design of new indicators for the wine sector [68] and others turn to specific single indicators as in the case of CF assessment [65,69].

In the literature, there are numerous studies that use the LCA methodology, which, thanks to the specific and detailed impact categories, are able to evaluate the environmental loads linked with different phases of the wine life cycle [63,65]. However, in order to make the results of LCA studies available to supply chain stakeholders and policy makers [70], the need to develop specific indicators, such as carbon footprint (CF) and water footprint (WF), has emerged in life cycle studies [71,72].

Indicators such as the CF and WF are increasingly widespread, which aim to assess the environmental impact related to the production and consumption of agri-food products [73,74]. The CF and WF analyses of the products are developed with an LCA analysis, which permits the assessment of the impacts “from the cradle to the grave”, according to the requirements of the respective international reference standards [12,13]. However, the function of a single indicator method, as in the case of the WF or the CF, in the dissemination of results has limits and risks associated with the representation of a single environmental impact [75,76]. This limit is much debated in the literature, which has overcome it as a single indicator, such as the CF, can still represent other underlying environmental impacts as it is strongly linked to the use of energy [76]. In the wine sector, the CF indicator is closely related to several environmental concerns and management processes [77].

Numerous articles are available in the literature that focus on conceptual and methodological aspects [78] or that use these indicators specifically in the wine sector [79,80]. As regards the WF, several case studies exist in the literature with a focus on both grape-wine production [81] and on the bottle of wine [82].

In the literature, the analysis of the CF is acquiring a role of great interest in the issues of sustainability in the wine sector [77]. This indicator offers both producers and consumers the opportunity to reduce uncertainties and information asymmetries within an increasingly globalized wine market [77]. The CF indicator, in fact, quantifies the greenhouse gas emissions that are the basis of the wine life cycle, taking into consideration all the phases of the product, from the agricultural phase of viticulture, to the transformation during winemaking, to the bottling, distribution and production of waste and by-products [77].

The literature analysing the CF is quite large and diverse [79,80,83], including both studies that perform a complete LCA analysis of a bottle of wine [74] and studies that instead focus on single stages of the production process [64,65,69,84–88], as well as others studying supply chain analysis [60,89] and others who instead carry out comparative analyses between the management of conventional and unconventional viticulture [90]. Furthermore, single problem approaches are commonly used in the literature, but a more comprehensive analysis should be employed instead, as a single indicator does not adequately track the pressure on the environment [74].

4.3. Environmental Impacts in the Agricultural Phase

The literature highlights the need for particular attention to vineyard management and therefore to the analysis of the life cycle delimited to the agricultural phase for grape production [15–20]. The research on the adoption of LCA in the wine sector has shown an unequivocal environmental hotspot in the agricultural phase [2] due to the wide use of different agronomic techniques [15–20], which require an extensive use of inputs [21].

The viticulture phase presents the widest range of variation in results among the impact categories considered. However, four categories of environmental impact are considered in all LCA studies in the wine sector: Carbon Footprint (CF), Abiotic Depletion (AD), Acidification Potential (AP) and Eutrophication Potential (EP). EP is the only impact category for which viticulture is the most impacting phase from an environmental point of view [22]. According to the literature on the analysis of the life cycle assessment in the wine sector, the planting phase of the vineyard is the one that represents the greatest impact on the CF of the wine and, on the contrary, the pre-production phase does not generate a

significant impact in this sense [73]. The use of nitrogen fertilizers and N₂O emissions are the factors that most determine the carbon footprint in the agricultural phase [73].

The review of the studies in the literature indicates the main wine hotspots in the agricultural phase of the vineyard due to the high inputs used in the vineyard (fuel, fertilizers and pesticides) [77]. Some authors have compared the management of wine production by comparing organic and conventional treatment [64,65,91–95], finding that the CF indicator value for organic wine “from the cradle to the door” is about 25% lower than for conventional wine [77].

Organic or biodynamic cultivation systems can significantly decrease the environmental impacts of viticulture [90] because they avoid the use of synthetic fertilizers and pesticides; moreover, the application of organic fertilizers improves the soil structure and closes the cycle of biological matter [91]. However, the results in the literature are not unanimous, both because viticulture is the phase with the widest variability of results and because the results are influenced by the definition of the functional unit. For example, the study carried out by Falcone et al. [92] shows that the combination of conventional practices with the espalier training system allows the best environmental performance thanks to the higher yield per hectare.

4.4. Environmental Impacts in the Vinification Phase

The environmental assessment in the vinification phase takes into consideration all the steps necessary for the wine production: transport of the grapes to the cellar; destemming and crushing; fermentation and filtration. Although the major environmental hotspot is in the agricultural phase, however, the transformation phase of wine production also generates considerable environmental impact, mainly due to the packaging materials used but also to the generation of products and waste [22]. Packaging production is the most impactful phase of the wine life cycle. The studies examined specified that the highest impact value (for all impact categories considered) was due in particular to the production of primary packaging production of glass bottles. Furthermore, the differences in the winemaking processes of the different types of wine in the studies examined do not determine high variations in environmental impacts to compete with the impacts produced by the other phases [22].

As regards the environmental performance of the types of white and red wine in terms of their carbon footprint (CF), the results of the studies are affected by a wide variability, and therefore it is difficult to define which type of wine is more sustainable from an environmental point of view. The results of the literature in this sense are not unanimous. On the one hand, some authors found that white wines perform slightly better in terms of CF than red wines thanks to the use of wooden barrels for aging during the storage period in the vinification phase [91]. The white winemaking phase, on the other hand, usually requires a process at a lower temperature, and this involves greater energy consumption. In light of this, this aspect requires further scientific investigation.

Logistics is also energy-intensive in the wine industry [89]. As noted in the literature, the emissions related to the delivery of wine are a significant part, but only a part of the total carbon emissions produced by a company [89]. With the growing attention on reducing greenhouse gas emissions, wineries are facing increasing pressure to demonstrate their commitment to minimizing their CF, also encouraging consumers to consider their own contributions [89]. Concerning the economic implications of introducing a CF label, it is necessary to consider the consumer’s awareness of this information and his purchasing behaviour for products that present such an indication of sustainability, which can lead to a change in the perceived qualitative characteristics of the product. On the one hand, the presence of these environmental indicators constitutes an element of differentiation that can lead the consumer to gain more awareness towards this quality attributes [96]. In this context, future studies should assess whether there exists a premium price for wines with a sustainable label. One of the conditions for eco-labels to be effective in the market

is that consumers are willing to pay a premium price to support the higher costs of more sustainable management those producers are called to sustain [97].

5. Conclusions

Environmental assessment in the wine sector offers benefits to both producers and consumers in an increasing globalization of the market. Specific indicators, such as the quantification of greenhouse gas emissions generated throughout the life cycle of wine, are increasingly required by the industry, which must respond to new and increasingly specific needs of consumers, who are increasingly attentive to sustainability issues in their decisions of purchases.

The present study offers a critical analysis of the literature on the use of the LCA method to evaluate the sustainability of the wine sector in order to highlight the main research areas, the trends of recent years and the new research trajectories on the subject.

The results of this study show that today the focus of the literature is on issues related to climate change and consumer awareness on sustainability issues and certifications, as well as environmental impacts generated mainly in the phase of agricultural production.

This bibliometric analysis provides key information for further developments in academic literature in the LCA topic in the wine supply chain. Furthermore, it has been found that this field is still underdeveloped, and scarce research has been conducted yet, so the topic needs further research. Moreover, another avenue for the academic world could be to compare LCA in viticulture and wine management with other marketing hypotheses, such as consumer involvement in LCA issues and the impacts generated in the wine supply chain. These concepts have been well considered in marketing [98,99], but research on this topic is still scarce.

The main limitation in this paper is due to the mapping citations and analysing clusters technique because one of the criteria was to include in the analysis only documents with at least four citations; therefore, current studies could be included in this research, regardless of their relative importance. For this reason, we suggest repeating the bibliometric analysis in the future to include also recent research to contribute to the discussion on the topic. Bibliometric analysis also has the limit of being too sensitive to the construction of the search query and to the selection of the data source, which limits it to a use mainly of an exploratory nature. Furthermore, the literature searching criteria, applied in the PRISMA procedure has inevitably excluded some papers on this topic.

Among the limitations of the study, it is important to highlight that the selected documents show a widespread variability in the definition of the system boundaries, and a lack of accessibility of original and site-specific inventory data in the LCA methodology. Furthermore, environmental impact values in the vineyard stage present a high variability, mainly due to the different types of production methods. The results could be influenced by other technical factors such as the grape variety, the pedoclimatic conditions, the chemical-physical characteristics of the soil and the climate. These variables can have a great influence on the results and may constitute a limitation of the present study and require further scientific input through future studies.

Future studies could investigate the environmental assessment linked to an intensification in the recycling rate of glass used for bottling but also the development of innovations such as lighter glass bottles or even the replacement of glass with different packaging materials that are at the same time suitable for preserving the quality of the wine. Ultimately, the attention to the sustainability of the wine sector for environmental assessment could therefore shift to the packaging phase that needs further investigation in the future. These indications suggest that future studies on the subject are needed.

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M.M., E.N. and M.D.; supervision, M.D. and G.C.; project administration, M.D. and G.C.; funding acquisition, G.C. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Overview of selected papers.

Authors	Title	Journal	Year
Agyemang et al.	Analysis of opportunities for greenhouse emission reduction in the global supply chains of cashew industry in West Africa	J. Clean Prod.	2016
Ahmad et al.	Integrated biorefinery approach to valorize winery waste: A review from waste to energy perspectives	Sci. Total Environ.	2020
Aivazidou and Tsolakis	A Water Footprint Review of Italian Wine: Drivers, Barriers, and Practices for Sustainable Stewardship	Water	2020
Aivazidou and Tsolakis	Investigating dynamic interconnections between organic farming adoption and freshwater sustainability	J. Environ. Manag.	2021
Aivazidou et al.	The emerging role of water footprint in supply chain management: A critical literature synthesis and a hierarchical decision-making framework	J. Clean Prod.	2016
Akbari et al.	Comparative life cycle energy and greenhouse gas footprints of dry and wet torrefaction processes of various biomass feedstocks	J. Environ. Chem. Eng.	2021
Aleixandre-Tudo et al.	Trends in funding research and international collaboration on greenhouse gas emissions: a bibliometric approach	Environ. Sci. Pollut. Res.	2021
Almeida et al.	Packaging environmental impact on seafood supply chains: A review of life cycle assessment studies	J. Ind. Ecol.	2021
Amienyo et al.	Environmental impacts of consumption of Australian red wine in the UK	J. Clean Prod.	2014
Anderson et al.	Production, Consumption, and Potential Public Health Impact of Low- and No-Alcohol Products: Results of a Scoping Review	Nutrients	2021
Aranda et al.	Economic and environmental analysis of the wine bottle production in Spain by means of life cycle assessment	Int. J. Agric. Resour. Gov. Ecol.	2005
Arcese et al.	Modeling Social Life Cycle Assessment framework for the Italian wine sector	J. Clean Prod.	2017
Ardente et al.	POEMS: A case study of an Italian wine-producing firm	Environ. Manag.	2006
Arvanitoyannis et al.	Life Cycle Assessment (ISO 14040) Implementation in Foods of Animal and Plant Origin: Review	Crit. Rev. Food Sci. Nutr.	2014
Arzoumanidis et al.	Considerations When Applying Simplified LCA Approaches in the Wine Sector	Sustainability	2014
Arzoumanidis et al.	Is there a simplified LCA tool suitable for the agri-food industry? An assessment of selected tools	J. Clean Prod.	2017

Table A1. *Cont.*

Authors	Title	Journal	Year
Arzoumanidis et al.	Unresolved issues in the accounting of biogenic carbon exchanges in the wine sector	J. Clean Prod.	2014
Aversa et al.	Design, manufacturing and preliminary assessment of the suitability of bioplastic bottles for wine packaging	Polym. Test	2021
Aversa et al.	Corotating twin-screw extrusion of poly(lactic acid) PLA/poly(butylene succinate) PBS/ micro-lamellar talc blends for extrusion blow molding of biobased bottles for alcoholic beverages	J. Appl. Polym. Sci.	2021
Aversa et al.	Injection-stretch blow molding of poly (lactic acid)/polybutylene succinate blends for the manufacturing of bottles	J. Appl. Polym. Sci.	2021
Bacenetti	Heat and cold production for winemaking using pruning residues: Environmental impact assessment	Appl. Energy	2019
Balafoutis et al.	Life Cycle Assessment of Two Vineyards after the Application of Precision Viticulture Techniques: A Case Study	Sustainability	2017
Bartocci et al.	Environmental impact of Sagrantino and Grechetto grapes cultivation for wine and vinegar production in central Italy	J. Clean Prod.	2017
Beauchet et al.	Inter-annual variability in the environmental performance of viticulture technical management routesa case study in the Middle Loire Valley (France)	Int. J. Life Cycle Assess.	2019
Becker et al.	The carbon neutrality principle: A case study in the French spirits sector	J. Clean Prod.	2020
Bellon-Maurel et al.	Streamlining life cycle inventory data generation in agriculture using traceability data and information and communication technologies—part II: application to viticulture	J. Clean Prod.	2015
Benedetto	The environmental impact of a Sardinian wine by partial Life Cycle Assessment	Wine Econ. Policy	2013
Benedetto et al.	Rebound effects due to economic choices when assessing the environmental sustainability of wine	Food Policy	2014
Benetto et al.	Life cycle assessment of heat production from grape marc pellets	J. Clean Prod.	2015
Bessou et al.	LCA applied to perennial cropping systems: a review focused on the farm stage	Int. J. Life Cycle Assess.	2013
Bonamente et al.	Environmental impact of an Italian wine bottle: Carbon and water footprint assessment	Sci. Total Environ.	2016
Bonamente et al.	The Water Footprint of the Wine Industry: Implementation of an Assessment Methodology and Application to a Case Study	Sustainability	2015
Bonilla-Gómez et al.	Environmental impact assessment of agro-services symbiosis in semiarid urban frontier territories. Case study of Mendoza (Argentina)	Sci. Total Environ.	2021
Borsato et al.	Comparison of Water-focused life Cycle Assessment and Water Footprint Assessment: The case of an Italian wine	Sci. Total Environ.	2019
Borsato et al.	Sustainable patterns of main agricultural products combining different footprint parameters	J. Clean Prod.	2018
Bosco et al.	Soil organic matter accounting in the carbon footprint analysis of the wine chain	Int. J. Life Cycle Assess.	2013
Bosco et al.	Greenhouse gas emissions in the agricultural phase of wine production in the Maremma rural district in Tuscany, Italy	Ital. J. Agron.	2011
Burja and Burja	Decisions In Sustainable Viticulture Using Life Cycle Assessment	J. Environ. Prot. Ecol.	2012

Table A1. Cont.

Authors	Title	Journal	Year
Bustamante et al.	Recycling of anaerobic digestates by composting: effect of the bulking agent used	J. Clean Prod.	2013
Canaj et al.	The economics of fruit and vegetable production irrigated with reclaimed water incorporating the hidden costs of life cycle environmental impacts	Resources	2021
Carrasco et al.	Greening Wine Exports? Changes in the Carbon Footprint of Spanish Wine Exports	Int. J. Environ. Res. Public Health	2021
Chemat et al.	Green extraction of natural products. Origins, current status, and future challenges	TrAC, Trends Anal. Chem.	2019
Chiriaco et al.	The potential carbon neutrality of sustainable viticulture showed through a comprehensive assessment of the greenhouse gas (GHG) budget of wine production	J. Clean Prod.	2019
Chiusano et al.	An Industrial Ecology approach to solve wine surpluses problem: the case study of an Italian winery	J. Clean Prod.	2015
Choque et al.	Impact of Spray-Drying on Biological Properties of Chitosan Matrices Supplemented with Antioxidant Fungal Extracts for Wine Applications	Curr. Microbiol.	2020
Cleary	A life cycle assessment of residential waste management and prevention	Int. J. Life Cycle Assess.	2014
Cleary	Life cycle assessments of wine and spirit packaging at the product and the municipal scale: a Toronto, Canada case study	J. Clean Prod.	2013
Cobut et al.	Reducing the environmental footprint of interior wood doors in non-residential buildings part-2: ecodesign	J. Clean Prod.	2015
Comandaru et al.	Life Cycle Assessment Of Wine: Focus On Water Use Impact Assessment	Environ. Eng. Manag. J.	2012
Cortes et al.	Unraveling the environmental impacts of bioactive compounds and organic amendment from grape marc	J. Environ. Manag.	2020
Cortes et al.	Environmental assessment of viticulture waste valorisation through composting as a biofertilisation strategy for cereal and fruit crops	Environ. Pollut.	2020
Cortes et al.	Integrated evaluation of wine lees valorization to produce value-added products	Waste Manag.	2019
Cuq et al.	Assessing macro-element content in vine leaves and grape berries of vitis vinifera by using near-infrared spectroscopy and chemometrics	Int. J. Environ. Anal. Chem.	2020
Cuq et al.	Assessing macro- (P, K, Ca, Mg) and micronutrient (Mn, Fe, Cu, Zn, B) concentration in vine leaves and grape berries of vitis vinifera by using near-infrared spectroscopy and chemometrics	Comput. Electron. Agric.	2020
D'Ammaro et al.	Benchmarking of carbon footprint data from the Italian wine sector: A comprehensive and extended analysis	Sci. Total Environ.	2021
D'Eusanio et al.	Social Organizational Life Cycle Assessment: an approach for identification of relevant subcategories for wine production in Italy	Int. J. Life Cycle Assess.	2020
de Almeida et al.	Ochratoxin A in Brazilian instant coffee	Braz. J. Microbiol.	2007
Dede et al.	A Statistical Framework for Assessing Environmental Performance of Quality Wine Production	Sustainability	2020
Demertzi et al.	Cork stoppers supply chain: potential scenarios for environmental impact reduction	J. Clean Prod.	2016

Table A1. *Cont.*

Authors	Title	Journal	Year
Deng et al.	Comparative analysis on environmental and economic performance of agricultural cooperatives and smallholder farmers: The case of grape production in Hebei, China	PLoS One	2021
Donia et al.	A methodological approach for assessing business investments in renewable resources from a circular economy perspective	Land Use Pol.	2018
Elhami et al.	Energy and environmental indices through life cycle assessment of raisin production: A case study (Kohgiluyeh and Boyer-Ahmad Province, Iran)	Renew. Energy	2019
Eren et al.	Determination Of Greenhouse Gas Emissions (Ghg) In The Production Of Different Fruits In Turkey	Fresenius Environ. Bull.	2019
Esposito et al.	Exploring Corporate Social Responsibility in the Italian wine sector through websites	TQM J.	2021
Falcone et al.	Assessment of Environmental and Economic Impacts of Vine-Growing Combining Life Cycle Assessment, Life Cycle Costing and Multicriterial Analysis	Sustainability	2016
Falcone et al.	Integrated sustainability appraisal of wine-growing management systems through LCA and LCC Methodologies	Chem. Eng. Trans.	2015
Ferrara and De Feo	Life Cycle Assessment Application to the Wine Sector: A Critical Review	Sustainability	2018
Ferrara and De Feo	Comparative life cycle assessment of alternative systems for wine packaging in Italy	J. Clean Prod.	2020
Ferrara et al.	Attitudes of a sample of consumers towards more sustainable wine packaging alternatives	J. Clean Prod.	2020
Ferrari et al.	Effects of grape quality on the environmental profile of an Italian vineyard for Lambrusco red wine production	J. Clean Prod.	2018
Ferreira et al.	Energy and resource efficiency of electroporation-assisted extraction as an emerging technology towards a sustainable bio-economy in the agri-food sector	J. Clean Prod.	2019
Ferreira et al.	Environmental advantages through producing energy from grape stalk pellets instead of wood pellets and other sources	Int. J. Environ. Sci.	2018
Flor et al.	Environmental impact of oak barrels production in Qualified Designation of Origin of Rioja	J. Clean Prod.	2017
Flor et al.	Environmental Impact of Wine Aging Process in Oak Barrels in Wineries of La Rioja (Spain)	Am. J. Enol. Vitic.	2018
Flor-Montalvo et al.	2-Piece Cork Stoppers as Alternative for Valorization of Thin Cork Planks: Analysis by LCA Methodology	Foods	2021
Flores	What is sustainability in the wine world? A cross-country analysis of wine sustainability frameworks	J. Clean Prod.	2018
Flores et al.	Carbon footprint of constructed wetlands for winery wastewater treatment	Ecol. Eng.	2020
Flores et al.	Constructed wetlands for winery wastewater treatment: A comparative Life Cycle Assessment	Sci. Total Environ.	2019
Fusi et al.	Delving into the environmental aspect of a Sardinian white wine: From partial to total life cycle assessment	Sci. Total Environ.	2014
Gallucci et al.	Environmental performance scenarios in the production of hollow glass containers for food packaging: an LCA approach	Int. J. Life Cycle Assess.	2021

Table A1. Cont.

Authors	Title	Journal	Year
Garcia-Alcaraz et al.	Comparative environmental impact analysis of techniques for cleaning wood wine barrels	Innov. Food Sci. Emerg. Technol.	2020
Garcia-Alcaraz et al.	Economic-environmental impact analysis of alternative systems for red wine ageing in re-used barrels	J. Clean Prod.	2020
Gazulla et al.	Taking a life cycle look at crianza wine production in Spain: where are the bottlenecks?	Int. J. Life Cycle Assess.	2010
Gierling and Blanke	Carbon reduction strategies for regionally produced and consumed wine: From farm to fork	J. Environ. Manag.	2021
Golsteijn and Vieira	Applicability of the European Environmental Footprint (EF) methodology in Southern Mediterranean countries-learnings and recommendations for enabling EF-compliant studies in regions outside of Europe	Int. J. Life Cycle Assess.	2020
Gonzalez-Garcia et al.	Combined application of LCA and eco-design for the sustainable production of wood boxes for wine bottles storage	Int. J. Life Cycle Assess.	2011
Gonzalez-Garcia et al.	Assessing the global warming potential of wooden products from the furniture sector to improve their ecodesign	Sci. Total Environ.	2011
González-García et al.	Comparative environmental and energy profiles of potential bioenergy production chains in Southern Europe	J. Clean Prod.	2014
Grassauer et al.	Eco-efficiency of farms considering multiple functions of agriculture: Concept and results from Austrian farms	J. Clean Prod.	2021
Gullon et al.	Comparative environmental Life Cycle Assessment of integral revalorization of vine shoots from a biorefinery perspective	Sci. Total Environ.	2018
Hallstrom et al.	Climate impact of alcohol consumption in Sweden	J. Clean Prod.	2018
Hamedani et al.	Comparative energy and environmental analysis of agro-pellet production from orchard woody biomass	Biomass Bioenerg.	2019
Harb et al.	Improving environmental performance in wine production by life cycle assessment: case of Lebanese wine	Int. J. Life Cycle Assess.	2021
Harris et al.	The impact of alternative routeing and packaging scenarios on carbon and sulphate emissions in international wine distribution	Transport. Res. Part D-Transport. Environ.	2018
Heller et al.	Mapping the Influence of Food Waste in Food Packaging Environmental Performance Assessments	J. Ind. Ecol.	2019
Herath et al.	Water footprinting of agricultural products: evaluation of different protocols using a case study of New Zealand wine	J. Clean Prod.	2013
Herath et al.	Water footprinting of agricultural products: a hydrological assessment for the water footprint of New Zealand's wines	J. Clean Prod.	2013
Hristov and Kuhar	Subjective knowledge as a determinant of young adult consumers wine behaviour	Br. Food J.	2015
Huang et al.	Production of Milk Phospholipid-Enriched Dairy Ingredients	Foods	2020
Iannone et al.	Improving environmental performances in wine production by a life cycle assessment analysis	J. Clean Prod.	2016
Iannone et al.	Life cycle assessment of red and white wines production in southern Italy	Chem. Eng. Trans.	2014
Jimenez et al.	Methodological approach towards sustainability by integration of environmental impact in production system models through life cycle analysis: Application to the Rioja wine sector	Simul.-Trans. Soc. Model. Simul. Int.	2014

Table A1. Cont.

Authors	Title	Journal	Year
Jourdaine et al.	A detailed quantitative comparison of the life cycle assessment of bottled wines using an original harmonization procedure	J. Clean Prod.	2020
Jradi et al.	Tracking carbon footprint in French vineyards: A DEA performance assessment	J. Clean Prod.	2018
Kounina et al.	The Importance of Considering Product Loss Rates in Life Cycle Assessment: The Example of Closure Systems for Bottled Wine	Sustainability	2012
Labbaci et al.	Treatment of Effluents Issued from Agro-Food Industries by Liquid-Liquid Extraction of Malic and Lactic Acids Using Tri-n-octylamine and Tri-n-butyl Phosphate	Ind. Eng. Chem. Res.	2012
Laca et al.	Assessment of the environmental impacts associated with vineyards and winemaking. A case study in mountain areas	Environ. Sci. Pollut. Res.	2021
Lamastra et al.	A novel fuzzy expert system to assess the sustainability of the viticulture at the wine-estate scale	Sci. Total Environ.	2016
Landi et al.	Life Cycle Assessment of an Innovative Technology against Late Frosts in Vineyard	Sustainability	2021
Laoretani et al.	On the conceptual modeling, economic analysis and life cycle assessment of partial dealcoholization alternatives of bitter extracts	Sep. Purif. Technol.	2020
Larrea-Gallegos et al.	Applying the Technology Choice Model in Consequential Life Cycle Assessment: A Case Study in the Peruvian Agricultural Sector	J. Ind. Ecol.	2019
Laureti and Benedetti	Exploring pro-environmental food purchasing behaviour: An empirical analysis of Italian consumers	J. Clean Prod.	2018
Leivas et al.	Environmental assessment of food and beverage under a NEXUS Water-Energy-Climate approach: Application to the spirit drinks	Sci. Total Environ.	2020
Licciardello	Packaging, blessing in disguise. Review on its diverse contribution to food sustainability	Trends Food Sci. Technol.	2017
Lin et al.	Torrefaction of fruit peel waste to produce environmentally friendly biofuel	J. Clean Prod.	2021
Litskas et al.	Determining the carbon footprint of indigenous and introduced grape varieties through Life Cycle Assessment using the island of Cyprus as a case study	J. Clean Prod.	2017
Litskas et al.	Sustainable Viticulture: First Determination of the Environmental Footprint of Grapes	Sustainability	2020
Litskas et al.	Determining the Carbon Footprint and Emission Hotspots for the Wine Produced in Cyprus	Atmosphere	2020
Liu et al.	Industrial metabolism analysis of a Chinese wine industry chain based on material flow and input-output analyses	J. Ind. Ecol.	2021
Longbottom and Petrie	Role of vineyard practices in generating and mitigating greenhouse gas emissions	Aust. J. Grape Wine Res.	2015
Manzardo et al.	Combination of product environmental footprint method and eco-design process according to ISO 14006: The case of an Italian winery	Sci. Total Environ.	2021
Marchal et al.	Purification and partial biochemical characterization of glycoproteins in a champenois Chardonnay wine	J. Agric. Food Chem.	1996
Margallo et al.	Life cycle assessment of technologies for partial dealcoholisation of wines	Sustain. Prod. Consump.	2015
Marras et al.	Carbon footprint assessment on a mature vineyard	Agric. For. Meteorol.	2015

Table A1. Cont.

Authors	Title	Journal	Year
Martín-Gamboa et al.	Delving into sensible measures to enhance the environmental performance of biohydrogen: A quantitative approach based on process simulation, life cycle assessment and data envelopment analysis	Bioresour. Technol.	2016
Martins et al.	Towards sustainable wine: Comparison of two Portuguese wines	J. Clean Prod.	2018
Martucci et al.	Social Aspects in the Wine Sector: Comparison between Social Life Cycle Assessment and VIVA Sustainable Wine Project Indicators	Resources	2019
Marvuglia et al.	SCALE: Software for CALCulating Emergy based on life cycle inventories	Ecol. Model.	2013
Mattila et al.	Uncertainty in environmentally conscious decision making: beer or wine?	Int. J. Life Cycle Assess.	2012
Mattila et al.	Land use indicators in life cycle assessment A case study on beer production	Int. J. Life Cycle Assess.	2012
Mattsson et al.	Waste of fresh fruit and vegetables at retailers in Sweden-Measuring and calculation of mass, economic cost and climate impact	Resour. Conserv. Recycl.	2018
Mazzoni et al.	Catalytic Biorefining of Ethanol from Wine Waste to Butanol and Higher Alcohols: Modeling the Life Cycle Assessment and Process Design	ACS Sustain. Chem. Eng.	2019
Meneses et al.	Sensitivity analysis in a life cycle assessment of an aged red wine production from Catalonia, Spain	Sci. Total Environ.	2016
Merli et al.	Sustainability experiences in the wine sector: toward the development of an international indicators system	J. Clean Prod.	2018
Moccia	Operational Research in the Wine Supply Chain	Infor	2013
Mohseni et al.	Coupled life cycle assessment and data envelopment analysis for mitigation of environmental impacts and enhancement of energy efficiency in grape production	J. Clean Prod.	2018
Molina-Besch	Prioritization guidelines for green food packaging development	Br. Food J.	2016
Molina-Besch et al.	The environmental impact of packaging in food supply chains does life cycle assessment of food provide the full picture?	Int. J. Life Cycle Assess.	2019
Monari et al.	Cascade strategies for the full valorisation of Garganega white grape pomace towards bioactive extracts and bio-based materials	PLoS ONE	2020
Montalvo et al.	Environmental impact of wine fermentation in steel and concrete tanks	J. Clean Prod.	2021
Morais et al.	Regionalization of agri-food life cycle assessment: a review of studies in Portugal and recommendations for the future	Int. J. Life Cycle Assess.	2016
Moreno and Dufour	Life cycle assessment of hydrogen production from biomass gasification. Evaluation of different Spanish feedstocks	Int. J. Hydrog. Energy	2013
Moreno-Garcia et al.	Environmental sustainability assessment of rice management practices using decision support tools	J. Clean Prod.	2021
Mostashari-Rad et al.	Energy optimization and greenhouse gas emissions mitigation for agricultural and horticultural systems in Northern Iran	Energy	2019
Nasser et al.	Phytochemical Profile, Antioxidant and Antitumor Activities of Green Grape Juice	Processes	2020
Navarro et al.	Tackling the Relevance of Packaging in Life Cycle Assessment of Virgin Olive Oil and the Environmental Consequences of Regulation	Environ. Manag.	2018

Table A1. Cont.

Authors	Title	Journal	Year
Navarro et al.	Product vs corporate carbon footprint: Some methodological issues. A case study and review on the wine sector	Sci. Total Environ.	2017
Ncube et al.	Upgrading wineries to biorefineries within a Circular Economy perspective: An Italian case study	Sci. Total Environ.	2021
Neto et al.	Life cycle assessment of the supply chain of a Portuguese wine: from viticulture to distribution	Int. J. Life Cycle Assess.	2013
Notarnicola et al.	Environmental and technical improvement of a grape must concentration system via a life cycle approach	J. Clean Prod.	2015
Otto et al.	Food packaging and sustainability—Consumer perception vs. correlated scientific facts: A review	J. Clean Prod.	2021
Pachón et al.	Conversion of vine shoots into bioethanol and chemicals: Prospective LCA of biorefinery concept	Bioresour. Technol.	2020
Paredes et al.	Screening of membrane technologies in concentration of bitter extracts with simultaneous alcohol recovery: An approach including both economic and environmental issues	Sep. Purif. Technol.	2020
Pascotto et al.	Fractionation and characterization of polyphenolic compounds and macromolecules in red wine by asymmetrical flow field-flow fractionation	J. Chromatogr. A	2020
Pattara et al.	Life Cycle Assessment and Carbon Footprint in the Wine Supply-Chain	Environ. Manag.	2012
Pattara et al.	Carbon footprint as an instrument for enhancing food quality: overview of the wine, olive oil and cereals sectors	J. Sci. Food Agric.	2017
Pedretti et al.	Sustainability of grape-ethanol energy chain	J. Agric. Eng.	2014
Pellegrini et al.	Application of water footprint to olive growing systems in the Apulia region: a comparative assessment	J. Clean Prod.	2016
Pena et al.	Modeling ecotoxicity impacts in vineyard production: Addressing spatial differentiation for copper fungicides	Sci. Total Environ.	2018
Peth et al.	Quantity- and Quality-Based Farm Water Productivity in Wine Production: Case Studies in Germany	Water	2017
Pizzigallo et al.	The joint use of LCA and emergy evaluation for the analysis of two Italian wine farms	J. Environ. Manag.	2008
Point et al.	Life cycle environmental impacts of wine production and consumption in Nova Scotia, Canada	J. Clean Prod.	2012
Ponstein et al.	How to increase sustainability in the Finnish wine supply chain? Insights from a country of origin based greenhouse gas emissions analysis	J. Clean Prod.	2019
Ponstein et al.	Greenhouse gas emissions and mitigation options for German wine production	J. Clean Prod.	2019
Postacchini et al.	Reuse of honey jars for healthier bees: Developing a sustainable honey jars supply chain through the use of LCA	J. Clean Prod.	2018
Quinteiro et al.	Addressing the freshwater use of a Portuguese wine ('vinho verde') using different LCA methods	J. Clean Prod.	2014
Ramos et al.	Environmental and socio-economic assessment of cork waste gasification: Life cycle and cost analysis	J. Clean Prod.	2020

Table A1. Cont.

Authors	Title	Journal	Year
Recchia et al.	Towards the environmental sustainability assessment for the viticulture	J. Agric. Eng.	2018
Renaud-Gentie et al.	Choosing the most representative technical management routes within diverse management practices: Application to vineyards in the Loire Valley for environmental and quality assessment	Eur. J. Agron.	2014
Renaud-Gentie et al.	Addressing organic viticulture environmental burdens by better understanding interannual impact variations	Int. J. Life Cycle Assess.	2020
Renaud-Gentié et al.	Pesticide emission modelling and freshwater ecotoxicity assessment for Grapevine LCA: adaptation of PestLCI 2.0 to viticulture	Int. J. Life Cycle Assess.	2015
Ridoutt et al.	Climate Change Adaptation Strategy in the Food Industry Insights from Product Carbon and Water Footprints	Climate	2016
Rinaldi et al.	Water and Carbon Footprint of Wine: Methodology Review and Application to a Case Study	Sustainability	2016
Ripoll et al.	Modelling of the anaerobic semi-continuous co-digestion of sewage sludge and wine distillery wastewater	Environ. Sci.-Wat. Res. Technol.	2020
Riva et al.	Sustainability of grape-ethanol energy chain	J. Agric. Eng.	2013
Rives et al.	Environmental analysis of the production of natural cork stoppers in southern Europe (Catalonia-Spain)	J. Clean Prod.	2011
Rives et al.	Integrated environmental analysis of the main cork products in southern Europe (Catalonia-Spain)	J. Clean Prod.	2013
Rodrigues et al.	Elemental analysis for categorization of wines and authentication of their certified brand of origin	J. Food Compos. Anal.	2011
Roibas et al.	Determination of the carbon footprint of all Galician production and consumption activities: Lessons learnt and guidelines for policymakers	J. Environ. Manag.	2017
Roselli et al.	Environmental and Economic Sustainability of Table Grape Production in Italy	Sustainability	2020
Rosi et al.	Adherence to the mediterranean diet and environmental impact of the diet on primary school children living in Parma (Italy)	Int. J. Environ. Res. Public Health	2020
Rouault et al.	Life Cycle Assessment Of Viticultural Technical Management Routes (Tmrs): Comparison Between An Organic And An Integrated Management Route	J. Int. Sci. Vigne Vin.	2016
Rouault et al.	Using LCA in a participatory eco-design approach in agriculture: the example of vineyard management	Int. J. Life Cycle Assess.	2020
Rugani et al.	A comprehensive review of carbon footprint analysis as an extended environmental indicator in the wine sector	J. Clean Prod.	2013
Ruggieri et al.	Recovery of organic wastes in the Spanish wine industry. Technical, economic and environmental analyses of the composting process	J. Clean Prod.	2009
Russo et al.	Exploring sustainability potentials in vineyards through LCA? Evidence from farming practices in South Africa	Int. J. Life Cycle Assess.	2021
Sabino et al.	In vitro and in vivo toxicological study of the Pterodon pubescens seed oil	Toxicol. Lett.	1999
Sanchez et al.	Bioethanol Production from Cachaza as Hydrogen Feedstock: Effect of Ammonium Sulfate during Fermentation	Energies	2017

Table A1. Cont.

Authors	Title	Journal	Year
Santos et al.	Regionalized Terrestrial Ecotoxicity Assessment of Copper-Based Fungicides Applied in Viticulture	Sustainability	2018
Saraiva et al.	Water Footprint Sustainability as a Tool to Address Climate Change in the Wine Sector: A Methodological Approach Applied to a Portuguese Case Study	Atmosphere	2020
Sardaro et al.	Latent relationships between environmental impacts of cultivation practices and land market: Evidences from a spatial quantile regression analysis in Italy	J. Clean Prod.	2021
Schlich and Fleissner	The ecology of scale: Assessment of regional energy turnover and comparison with global food	Int. J. Life Cycle Assess.	2005
Scrucca et al.	Uncertainty in LCA: An estimation of practitioner-related effects	J. Clean Prod.	2020
Shimako et al.	Operational integration of time dependent toxicity impact category in dynamic LCA	Sci. Total Environ.	2017
Shundo et al.	Ochratoxin A in wines and grape juices commercialized in the city of Sao Paulo, Brazil	Braz. J. Microbiol.	2006
Sierra-Perez et al. Gabarrell, X	Production and trade analysis in the Iberian cork sector: Economic characterization of a forest industry	Resour. Conserv. Recycl.	2015
Simon et al.	Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles	J. Clean Prod.	2016
Sinisterra-Solis et al.	Assessing the environmental impact of Spanish vineyards in Utiel-Requena PDO: The influence of farm management and on-field emission modelling	J. Environ. Manag.	2020
Smedman et al.	Nutrient density of beverages in relation to climate impact	Food Nutr. Res.	2010
Soosay et al.	Sustainable value chain analysis—a case study of Oxford Landing from vine to dine	Supply Chain Manag.	2012
Steenwerth et al.	Life cycle greenhouse gas, energy, and water assessment of wine grape production in California	Int. J. Life Cycle Assess.	2015
Sun and Drakeman	Measuring the carbon footprint of wine tourism and cellar door sales	J. Clean Prod.	2020
Testa et al.	Giant reed as energy crop for Southern Italy: An economic feasibility study	Renew. Sust. Energ. Rev.	2016
Thompson-Witrick et al.	The Impact Packaging Type Has on the Flavor of Wine	Beverages	2021
Timpanaro et al.	Sustainability as a business strategy in sicilian viniculture	Quality-Access to Success	2016
Tobiszewski and Namieśnik	Direct chromatographic methods in the context of green analytical chemistry	TrAC, Trends Anal. Chem.	2012
Torres et al.	Greenhouse gas calculator at farm level addressed to the growers	Int. J. Life Cycle Assess.	2017
Trombly and Fortier	Carbon Footprint of Wines from the Finger Lakes Region in New York State	Sustainability	2019
Tsangas et al.	Life Cycle Analysis in the Framework of Agricultural Strategic Development Planning in the Balkan Region	Sustainability	2020
Vazquez-Rowe et al.	Joint life cycle assessment and data envelopment analysis of grape production for vinification in the Rias Baixas appellation (NW Spain)	J. Clean Prod.	2012
Vazquez-Rowe et al.	Life Cycle Assessment of the production of pisco in Peru	J. Clean Prod.	2017

Table A1. Cont.

Authors	Title	Journal	Year
Vazquez-Rowe et al.	Environmental analysis of Ribeiro wine from a timeline perspective: Harvest year matters when reporting environmental impacts	J. Environ. Manag.	2012
Vazquez-Rowe et al.	Assessing the magnitude of potential environmental impacts related to water and toxicity in the Peruvian hyper-arid coast: A case study for the cultivation of grapes for pisco production	Sci. Total Environ.	2017
Vazquez-Rowe et al.	Environmental profile of green asparagus production in a hyper-arid zone in coastal Peru	J. Clean Prod.	2016
Vazquez-Rowe et al.	Tapping carbon footprint variations in the European wine sector	J. Clean Prod.	2013
Vázquez-Rowe et al.	Joint life cycle assessment and data envelopment analysis of grape production for vinification in the Rías Baixas appellation (NW Spain)	J. Clean Prod.	2012
Vega et al.	Insights from combining techno-economic and life cycle assessment—a case study of polyphenol extraction from red wine pomace	Resour. Conserv. Recycl.	2021
Vega et al.	Maximizing Environmental Impact Savings Potential through Innovative Biorefinery Alternatives: An Application of the TM-LCA Framework for Regional Scale Impact Assessment	Sustainability	2019
Vendrame et al.	Study of the Carbon Budget of a Temperate-Climate Vineyard: Inter-Annual Variability of CO ₂ Flux	Am. J. Enol. Vitic.	2019
Villanueva-Rey et al.	Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain	J. Clean Prod.	2014
Villanueva-Rey et al.	Regionalizing eco-toxicity characterization factors for copper soil emissions considering edaphic information for Northern Spain and Portuguese vineyards	Sci. Total Environ.	2019
Villanueva-Rey et al.	Accounting for time-dependent changes in GHG emissions in the Ribeiro appellation (NW Spain): Are land use changes an important driver?	Environ. Sci. Policy	2015
Villanueva-Rey et al.	Assessing water footprint in a wine appellation: A case study for Ribeiro in Galicia, Spain	J. Clean Prod.	2018
Wong et al.	Sustainable consumption and production: Modelling product carbon footprint of beverage merchandise using a supply chain input-process-output approach	Corp. Soc. Responsib. Environ. Manag.	2021
Zhang and Rosentrater	Estimating Economic and Environmental Impacts of Red-Wine-Making Processes in the USA	Fermentation	2019

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