Cleaner Environmental Systems 12 (2024) 100156

Contents lists available at ScienceDirect

Cleaner Environmental Systems

journal homepage: www.journals.elsevier.com/cleaner-environmental-systems

Application of the LCA approach to the citrus production chain – A systematic review

Giacomo Falcone [*], Antonio Fazari, Gregorio Vono, Giovanni Gulisano, Alfio Strano

Dipartimento di Agraria, Università Degli Studi Mediterranea di Reggio Calabria, 89122, Reggio, Calabria, Italy

ARTICLE INFO

Keywords:
LCA
Citrus supply chain
Functional unit
System boundaries
Data quality
Life cycle inventory

ABSTRACT

The citrus sector represents one of the main agri-food supply chains in Italy, which today is the second largest producer of citrus fruits in Europe. Consequently, its impact from an environmental, economic and social point of view can be considerable and it is therefore necessary to assess the sustainability performance of this supply chain. Life Cycle Assessment (LCA) studies are nowadays an important tool for the improvement of production standards and for better decision support by entrepreneurs and public decision makers. This work aims to review in a systematic way the scientific literature on LCA applied to the citrus fruit sector and was conducted following the STARR-LCA checklist approach. The survey was conducted through the main bibliographic databases: Scopus, Web Of Science and Google Scholar, adopting specific search criteria depending on the tool used; the search led to a final selection of 42 articles. The analysis of the papers was conducted using various parameters such as: topic, methodology applied, system boundaries, functional units, allocation criteria, inventory analysis and impact assessment. The analysis of the results shows an overview of the state of the art of LCA approach applied to the citrus sector and can provide useful data and information for practitioners as well as a basis for further methodological developments.

1. Introduction

Agri-food chains are complex networks of activities and relationships linking producers, processors, distributors and final consumers. They are hierarchical organisations in which producers are at the bottom of the chain and final consumers are at the top (Falcone et al., 2020a).

Agri-food chains play a fundamental role in the economy of an area, as they contribute to the creation of added value and jobs, representing an important economic engine for rural and peripheral areas, which often do not fully exploit their potential. For this reason, the creation of sustainable and competitive agri-food chains contributes to reducing unemployment and promoting local economic activities, enabling small producers to access new markets and increase their turnover and investment perspectives (Gulisano et al., 2018).

Unlike other agricultural production which is generally represented by the cultivation of a plant species, the citrus fruit sector is represented by a very heterogeneous production which can be sub-categorised according to the family of citrus fruit cultivated.

At international level, citrus fruit production is usually divided into: orange production; lemon and lime production; grapefruit production; mandarin and mandarins-like (clementines, tangerines and satsumas) production; minor citrus fruit production, including bergamot, chinotto, kumquat, etc.; and citrus fruit production of the other citrus fruit families (Faostat, 2021).

A total of more than 11 million hectares were cultivated with citrus fruits worldwide as of 2018. Europe is the second-last continent in terms of areas devoted to citrus cultivation, however, in the Mediterranean countries, citrus cultivation has a thousand-year-old tradition, introduced mainly by the Saracens, who started growing citrus fruits as early as the 10th century. In terms of both surface area and production and yields, the citrus fruit sector is dominated by Spain, which is Europe's leading producer of citrus fruit, and Italy, which is Europe's leading producer of mandarins and mandarin-like citrus fruit (Faostat, 2022).

Sustainability of the citrus supply chain involves adopting farming and management practices that protect the environment, preserve the health of workers and promote the economic development of local communities. This includes the use of organic farming methods, sustainable water management, the promotion of fair and decent working conditions for farm workers, improved logistics and transport of produce, and the reduction of greenhouse gas emissions. In this context, it is

* Corresponding author.
E-mail address: giacomo.falcone@unirc.it (G. Falcone).

https://doi.org/10.1016/j.cesys.2023.100156
Received 28 February 2023; Received in revised form 12 November 2023; Accepted 29 November 2023
Available online 8 December 2023

essential to identify tools for evaluating and designing citrus production processes in a sustainable way.

Life cycle tools are among the most effective in this context, allowing scholars to define environmental sustainability performance (Life Cycle Assessment - LCA), economic sustainability (Life Cycle Costing - LCC) and social sustainability performance (Social Life Cycle Assessment - SLCA) (Stillitano et al., 2021).

Among these tools, the LCA approach (ISO, 2006a; ISO, 2006b)is certainly the one that is receiving the most attention from the international scientific community and finds application in all sectors of the economy.

The agri-food sector is one of the sectors most vibrantly interested in LCA studies and is characterised by some peculiar aspects that differentiate it from others, mainly due to the biological nature of its production processes (Notarnicola et al., 2015). This implies a strong link between the production process and the environment where it is conducted, so the processes are neither repeatable nor generalisable. This poses a strong problem for LCA practitioners in the agro-food sector, because they have to model production processes on the basis of site-specific data and design the life cycle model according to the specific production reality they have to analyse (Notarnicola et al., 2015).

These aspects are amplified when one goes beyond the generalist view of the citrus sector, which, as previously specified, represents a heterogeneous group of products and processes ranging from fruit production for fresh consumption to industrial processing, including the production of derivative products (e.g., essential oils, pectin, vitamins) and the valorisation of by-products. The concept of the product life cycle urges us to broaden the analysis perspective by including the various stages that can represent a link in the production and distribution chain of a specific citrus product. The life cycle of orange juice will be profoundly different from that of fresh oranges, so it is essential to provide an overview that represents the current state of research on the life cycle assessment of the various products that characterize the citrus sector. This will help explore the methodological approaches adopted by different scholars who have studied this sector, understand the challenges in applying life cycle assessment methodology to this industry, and highlight the remaining open questions regarding the issues that characterize this topic.

In this context, the aim of this paper is to deepenthe different methodological approaches implemented for the study of this complex supply chain and verify the availability of inventory data relating to the Italian production of citrus fruits. Therefore a review analysis was carried out to know the state-of-the-art of national and international research on the application of the LCA approach to the citrus sector. Results of review can be valuable to a wide range of stakeholders, as it provides a comprehensive overview of the existing research, insights, and findings in this specific area. LCA practitioners can use the literature review results to identify gaps in existing research and potential areas for future investigation, but also as methodological guidance and repository of specific inventory data. Citrus growers and agribusinesses can gain insights into best practices for sustainable citrus production and processing, which can help them reduce environmental impacts, enhance product quality, and comply with regulatory requirements. Policymakers can use the results to make informed decisions about regulations and incentives related to the citrus sector's sustainability and environmental impact. Informed consumers can use the literature review to make more sustainable choices when purchasing citrus products.

2. Description of the review protocol

This systematic review focuses on citrus (cultivation and production) LCA literature and was carried out through a systematic review using the STARR-LCA checklist approach proposed by (Zumsteg et al., 2012). According to the authors' proposals, the systematic approach to be followed for a review on the issues of life cycle analysis must include nine distinct phases.

1) Review Title, Keywords, and Abstract: Effective titles and keywords are essential for report discovery, especially in systematic reviews. The abstract should include nine essential components, including background, objectives, data sources, study eligibility criteria, and more, tailored to the field's requirements.
2) Rationale for the Review: The review's significance should be justified on the basis of existing knowledge and should be explained how it contributes to a broader understanding within various backgrounds and disciplines.
3) Review Question and Objectives: Clear, concise, and answerable questions should be constructed, employing established strategies or alternative methods to define key components or scope. As structured question formats (Zumsteg et al., 2012) suggest PIFT structure as follow:
   Product - definition of the product or process category being assessed.
   Impact – definition of the impacts of interest.
   Flow – definition of the flows or economic sectors contributing to the impact.
   Type – definition of the types of LCA of interest
4) Description of Systematic Review Protocol: A detailed protocol should be provided, outlining how the review will be conducted, addressing factors like search strategies, criteria for inclusion/exclusion, data recording, and any planned meta-analyses.
5) Findings and Features of Individual Studies: Essential information about the included studies or data sources, highlighting strengths, weaknesses, and relevant insights to aid the reader's understanding should be provided. Visual representations, such as tables or plots, can be beneficial.
6) Assessment of Bias: Authors of review should recognize and evaluate bias at two levels: within individual studies and across multiple studies, particularly concerning publication bias and sources of bias specific to the field.
7) Synthesis Methods (Qualitative and Quantitative): Diverse methods can be employed for synthesizing evidence, ranging from qualitative to quantitative approaches. Any adjustments made in meta-analyses should be explained and their impact on study variability estimated.
8) Limitations of the Review: Limitations, considering factors like time frame, geography, and technology type should be highlighted and discussed. Authors should discuss also the applicability of findings based on the review's scope and use limitations as opportunities for identifying future research questions.
9) Summary of Findings and Conclusions: The core evidence should be summarized, providing a broad interpretation in the context of existing knowledge, with a focus on practical problem-solving and policy implications.

The review was conducted through the main bibliographic databases: Scopus, Web Of Science, and Google Scholar adopting specific search criteria depending on the tool used. On Scopus and Web Of Science, it has researched the literature from 10 years (2012–2021), through the use of advanced research queries that allowed only the identification of works consistent with research. The analysis of the scientific literature also included the search for works not indexed on Scopus and Web Of Science; therefore, a search was conducted on Google Scholar in order to identify the "grey literature" useful to provide data on the application of the LCA approach to the citrus-fruit sector. The time horizon was restricted to five years (2017–2021), excluding patents and citations. The specific objective of the search through this tool was to identify specific literature containing inventory data of application studies on national productions that could not be found on the previously used databases. According to the specificities of the search engines of the individual bibliographic databases, advanced search strings were used by entering title, abstract and keywords as search fields (Table 1). Considering the complexity of the citrus sector, which includes a multitude of different products, and the peculiarities of the Google scholar, which does not allow to exclude the bibliography of each product from the search, the search led to several articles exceeding 20,000. Therefore, it was not possible to make a suitable selection. Based on this consideration, differentiated searches were carried out, depending on the keywords sought, to manage a reasonable number of results. Other research results that emerged by the strings used in Google scholar, although consistent with the research objectives, were discarded because they referred to a period prior to 2017.

To highlight the papers related to Italian productions on both databases, the words "Italy OR Italian" have been added to the strings, an integration that has obtained a result of 10 titles on Scopus and 13 on Web Of Science. The results of the databases have been filtered, eliminating duplication. The total papers resulting from the research was 102 products. By eliminating all the results inconsistent with the research objective, a first selection of the titles was made. Subsequently a further selection on the contents was made, thus selecting 67 works useful for the analysis of the literature. A digital version of each work was downloaded and catalogued according to a corresponding ID.

The protocol provided for an analysis of the contents of each scientific contribution, resulting in the rejection of the works that had as their object of study only the citrus industry derivatives not belonging to the citrus sector such as the extraction of chemical components, enhancement of some by-products, etc. or papers that did not apply the LCA approach.

The final selection of articles useful for drafting the review was performed through a quantitative qualitative analysis of the aspects that characterize the LCA studies. Specifically, the following aspects have been considered: product analysed, cultivation method, typology of the study, applied methodology, objectives and scope of the study, impact assessment methods, impact assessment phases, impact categories, system boundaries, specific system phases, exclusions, geographical and temporal boundaries, presence of inventory data, type of primary and secondary data, databases used and bibliographic references, data quality analysis, emission models used, contribution analysis, sensitivity analysis and main results. The final selection included 42 articles (Fig. 1), all of which were individually uploaded to a table to highlight their distinctive characteristics (Supplementary material).

Table 1
Parameters used in different search engines.

Search engines	Search records	*Search fields: TITLE-ABS-KEY*
SCOPUS	96	*(life AND cycle AND assessment OR lca AND citrus OR orange OR lemon OR clementine OR grapefruit OR bergamot OR mandarine OR clementine OR tangerine OR satsuma OR Chinotto OR Citron)*
WEB OF SCIENCE	61	*TI=("life cycle assessment" OR LCA) AND TI=(citrus OR orange OR lemon OR clementine OR grapefruit OR bergamot OR mandarine OR clementine OR tangerine OR satsuma OR chinotto OR citron) OR (AB=("life cycle assessment" OR LCA) AND AB=(citrus OR orange OR lemon OR clementine OR grapefruit OR bergamot OR mandarine OR clementine OR tangerine OR satsuma OR chinotto OR citron) OR KP=("life cycle assessment" OR LCA) AND KP=(citrus OR orange OR lemon OR clementine OR grapefruit OR bergamot OR mandarine OR clementine OR tangerine OR satsuma OR chinotto OR citron) OR AK=("life cycle assessment" OR LCA) AND AK=(citrus OR orange OR lemon OR clementine OR grapefruit OR bergamot OR mandarine OR clementine OR tangerine OR satsuma OR chinotto OR citron)).*
GOOGLE SCHOLAR (Grey literature)	9610	*Chinotto OR citrus OR orange OR lemon OR clementine OR grapefruit OR bergamot OR mandarine OR clementine OR tangerine OR satsuma "LCA"*
	1600	*Chinotto OR citrus OR orange OR lemon OR clementine OR grapefruit OR bergamot OR mandarine OR clementine OR tangerine OR satsuma "LIFE CYCLE ASSESSMENT"*
	1600	*Ital Chinotto OR citrus OR orange OR lemon OR clementine OR grapefruit OR bergamot OR mandarine OR clementine OR tangerine OR satsuma "LIFE CYCLE ASSESSMENT"*
	259	*agrume OR arancia OR limone OR clementina OR cedro OR pompelmo OR mandarino OR bergamotto OR Chinotto "LIFE CYCLE ASSESSMENT"*
	103	*agrumi OR arance OR limoni OR clementine OR cedri OR pompelmi OR mandarini OR bergamotti OR Chinotti "LIFE CYCLE ASSESSMENT" (0 Italiano)*
	28	*agrumi OR arance OR limoni OR clementine OR cedri OR pompelmi OR mandarini OR bergamotti OR Chinotti "LCA" (0 Italiano)*

3. Findings and features of the individual studies in the review

The selected articles underwent an evaluation process based on the product under study and the type of study conducted. About the product, among the analysed studies, 9 evaluated management and/or valorisation processes of citrus industry by-products (eg. Ortiz et al., 2020; Joglekar et al., 2019), 8 are related to life cycle analyses of clementines (eg. Falcone et al., 2020b; Basset-Mens et al., 2016), 7 focused on the impacts of oranges (eg. Martin-Gorriz et al., 2020; Ogunlade et al., 2020), 5 on citrus juices (4 orange juice and 1 lemon juice) (eg. Cacace et al., 2020; Arzoumanidis et al., 2017), 3 assess the impacts of multiple citrus fruits (eg. Frankowska et al., 2019), 3 focus on citrus fruits of minor commercial importance (lemon, grapefruit, and bergamot) (eg. Strano et al., 2017), while 6 refer to citrus fruits without reporting detailed product information (eg. Mostashari-Rad et al., 2021) (Table 2).

With reference to the type of study conducted, most of the papers have an applicative approach (20) (eg. Yang et al., 2020; Alishah et al., 2019; Bell et al., 2018) and the remaining part is comparative (15) (eg. Mostashari-Rad et al., 2020; Maestre-Valero et al., 2018; de Luca et al., 2014), methodological (4) or mixed (1 methodological/applicative and 1 applicative/comparative) (eg. Ramos et al., 2016; Bessou et al., 2016) (Fig. 2).

The evaluation of the papers that include the citrus cultivation phase in the analysis system revealed that the cultivation method was not specified in 15 of them (eg. Mostashari-Rad et al., 2021; Notarnicola et al., 2017), in 8 only the productions with conventional management were evaluated (eg. Nicolo et al., 2017; Yan et al., 2016) and in 9 the productions derived from both conventional and organic management (eg. Ribal et al., 2019; Aguilera et al., 2015). Only 3 articles contain information on conventional, organic and integrated cultivation citrus crop systems (eg. Falcone et al., 2020b; de Luca et al., 2015) and one paper focused on the evaluation of integrated managment (lo Giudice et al., 2013). In relation to the applied methodology, the analysis revealed that 24 works are carried out applying only the LCA approach, 22 studies use the LCA attributional methodology (eg. Garcia-Garcia et al., 2019; Knudsen et al., 2011) and one the consequential LCA approach (Negro et al., 2017). In a single project, conducted by Arzoumanidis et al. (2017), the application of several simplified LCA tools is tested. The examination of the papers also revealed the use of joint methodologies such as: LCA and LCC methodologies (4) (eg. Pergola et al., 2013), LCA and Cost of Production (2) (eg. Martinez-Hernandez et al., 2019), LCA and DEA (1) (Beltrán-Esteve et al., 2017), LCA and Energy balance (1) (Alishah et al., 2019), LCA and Exergy Analisys (2) (Mostashari-Rad et al., 2020, 2021). The other papers use other life cycle analysis methodologies. In particular, two studies apply the Carbon Footprint together with the Energy analysis (Bell et al., 2018; Maestre-Valero et al., 2018), one the Carbon Footprint

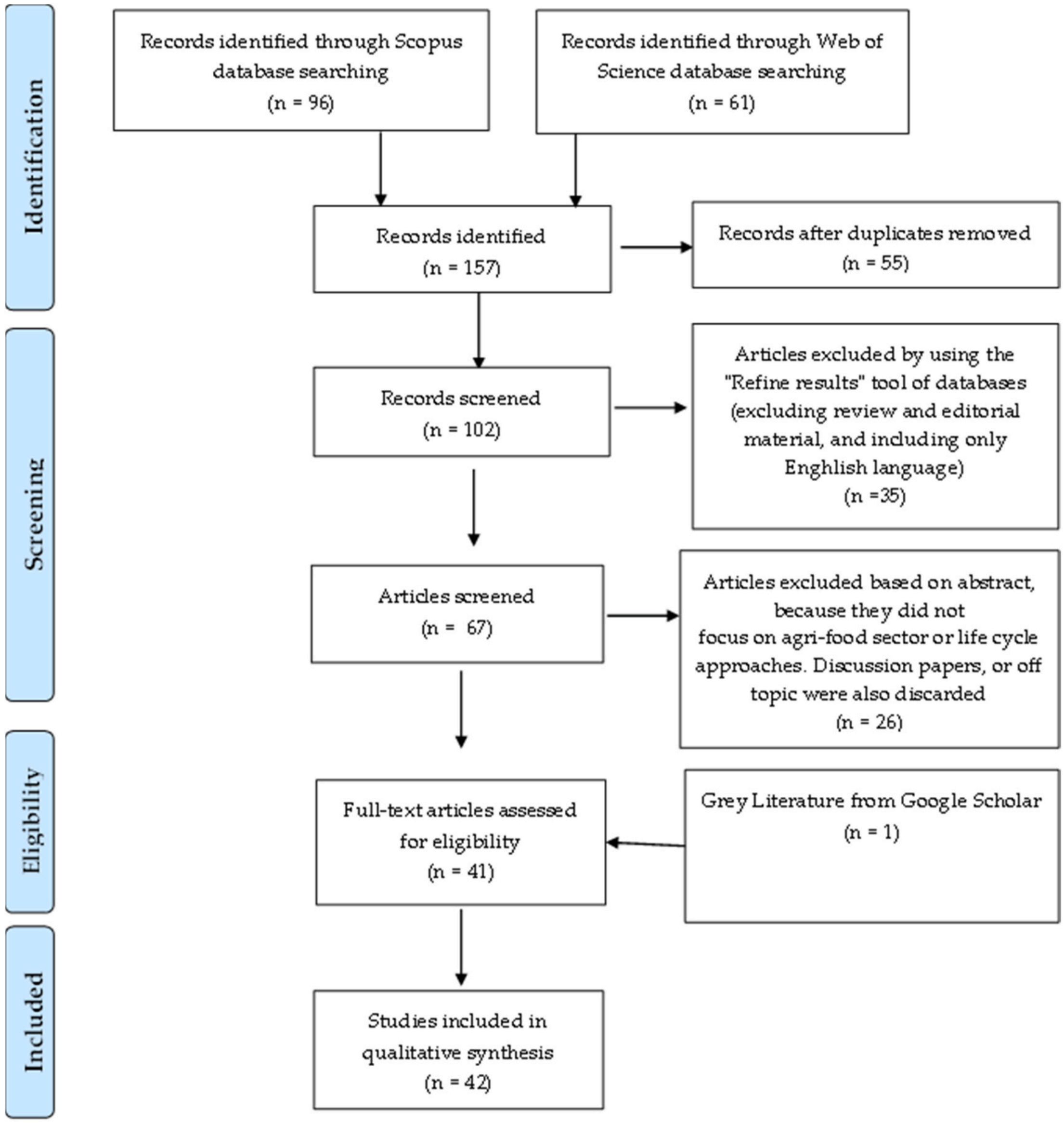

Fig. 1. Methodological steps of the literature search process.

(Yan et al., 2016) and one the Energy Analysis (Ogunlade et al., 2020). Two studies reporting inventory data also useful for environmental analysis were involved in the analysis despite applying the SLCA methodology (de Luca et al., 2015; Iofrida et al., 2019) (Fig. 3).

From the analysis of Google scholar records, all products already present in Scopus and Web Of Science searches were discarded, and only works with explicit reference to LCA analyses concerning products of the Italian citrus fruit chain and reporting primary inventory data were selected. Only one useful paper was identified with the objective of assessing through LCA approach 5 categories of orchards (olive, orange, almond, peach and apple) (Montanaro et al., 2017).

3.1. Analysis of the objectives and the field of application

After a general analysis of the selected papers, we proceeded to focus on and classify specific aspects of the LCA approach, in accordance with the key elements that characterize the analysis framework in four distinct phases. Each study is characterized by specific objectives and fields of application, and it would therefore be of little use to describe them individually. On the basis of this consideration, the analysis was conducted by grouping the works according to the common points relating to the proposed aims. The evaluation of one or more products represents the general objective of most (25 papers) of the literature considered. Specifically, the aims were to define the eco-profile of the products or to analyse one or more specific impact categories (eg. Nicolò et al., 2018; Ribal et al., 2017). These are classic application and/or comparative studies analysing the environmental performance of one or more agricultural or industrial products. Eight of the 41 studies have as their stated objective the evaluation of citrus industry waste management scenarios (eg. Durkin et al., 2019; Zhang et al., 2018a). These works deserve to be considered separately from the applications described above as processing waste management is generally outside the system boundaries analysed. Therefore, although these are also analyses of the environmental performance of different waste management/valorisation scenarios, they should be considered separately as they analyse an extension of the citrus fruit life cycle that is normally neglected.

Five studies have methodological development and/or implementation as their main objective; citrus cultivation is, therefore, not the focus of the work, but a case study to test the validity of the tested methodologies (eg. Bessou et al., 2016). Two articles deserve to be mentioned separately as they analyse the environmental profiles of

Table 2
Papers per product analysed.

Products	Number of papers
Bergamot	1
Citrus farms	1
Citrus pectine's	1
Citrus Unspecified	3
Clementines	8
Grapefruit	1
Hazelnut, citrus, tea, kiwifruit and watermelon	2
Lemon juice	1
Lemons	1
NFC Orange Juice	1
Orange juice	3
Oranges	7
Oranges and lemon	1
Oranges, lemons and mandarines	1
Peel waste	5
PLC from citrus wastes	3
Artichoke, broccoli, lettuce and melonlemon, orange, mandarin, apricot and peach	1
Total	**41**

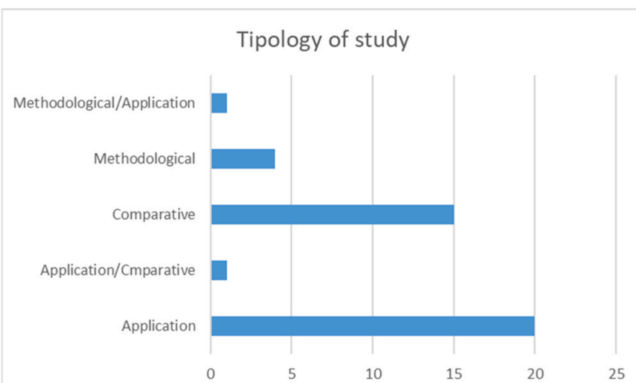

Fig. 2. Tipology of studies performed.

citrus fruits in a broader context of food consumption (Frankowska et al., 2019; Notarnicola et al., 2017).

In relation to the analysed system boundaries, most studies considered a partial life cycle perspective; in fact 27 papers considered the system boundaries "from cradle to gate" (eg. Knudsen et al., 2011; Nicoló et al., 2015) and three "from gate to grave" (eg. Eriksson and Spångberg, 2017). Only 11 papers adopted a "from cradle to grave" perspective (eg. Zhang et al., 2018b; Dwivedi et al., 2012) and among these it should be specified that 3 consider the complete life cycle of the citrus orchard (Strano et al., 2017; de Luca et al., 2014; Pergola et al., 2013) offering therefore always a partial assessment of the product life cycle. "From cradle to gate" studies always consider the agricultural production phase (eg. Basset-Mens et al., 2016), almost always excluding from the boundaries the conditioning or processing, distribution, use and end-of-life phases. Only one work extends the boundaries to the gate of the air conditioning centre (Nicolo et al., 2017). The "from gate to grave" studies all refer to the end-of-life phase, excluding the production and distribution phases (eg. Garcia-Garcia et al., 2019). About 25% of the papers referred to Italian productions (eg. Falcone et al., 2020b; Nicolo et al., 2017) and about 16% to Spanish productions (eg. Aguilera et al., 2015; Ribal et al., 2017), while the rest of the papers had more heterogeneous geographical boundaries (eg. Yan et al., 2016) (Fig. 4). Remarkably, just 2 research papers focus on China, while 2 others concentrate on the United States as their geographical context. Additionally, three studies revolve around South American citrus production in countries like Brazil, Mexico, and Colombia, while another three pertain to Iran, and three more are centered on African countries, including Morocco and Nigeria. Several other studies explore regions with no significant citrus production, such as Canada, the United Kingdom, or Sweden. It's worth noting that these particular studies primarily delve into aspects like consumption, industrial processes, or waste management rather than the impacts on production. Furthermore, three studies lack a specific geographic reference, and two encompass broader geographic scopes like the global or European context.

Regarding the paper belonging to the grey literature (Montanaro et al., 2017), for all the products analysed in the study, a system boundary "from cradle to grave" is considered, however, including only the life cycle of the orchard. Therefore, the packaging and distribution phases of the products are excluded. In terms of time, only nine papers considered a multi-year time span (eg. de Luca et al., 2014; Bessou et al., 2016), while most of the rest evaluated only one production year (eg. Ogunlade et al., 2020). All papers in which the time span is not explicitly stated (e.g. Joglekar et al., 2019) are probably also among those that considered only one year. Only three papers include the nursery phase in the system boundaries (eg. Martin-Gorriz et al., 2020) and only one refers to a "detailed survey" at a nursery (Basset-Mens et al., 2016).

3.2. Definition of functional unit and data quality

The overall analysis of the selected papers showed that 23 of them used a mass unit (eg. Dwivedi et al., 2012), 9 used an area unit (eg. Strano et al., 2017), 6 used both mass and area units (eg. Yang et al., 2020), 2 used units of mass consumed (Frankowska et al., 2019; Notarnicola et al., 2017), and 1 used an energy functional unit for the evaluation of a waste valorisation process (Martinez-Hernandez et al., 2019).

Regarding data quality, the review process showed that only 8 studies did not use primary data (eg. Joglekar et al., 2019), while all the others relied on ad hoc data collection or data from the same authors published previously (eg. Zhang et al., 2018a). In relation to secondary data, all papers use specific bibliographic references, while Ecoinvent, mentioned in 29 of the 41 articles analysed, turns out to be the most used database (eg. Negro et al., 2017). Three articles state respectively the use of other databases such as the Indian database in the GaBi software (Joglekar et al., 2019), the Franklin Environmental Database and the TRACI database (Dwivedi et al., 2012). Two papers used Ecoinvent databases in combination with other datasets; specifically, the Agri-footprint DB (Notarnicola et al., 2017) the Agribalyse DB (Basset-Mens et al., 2016) were used. In addition, among the literature analysed, one paper reports a single bibliographic reference (Aguilera et al., 2015) while 8 others do not report the databases used (eg. Yang et al., 2020). Data quality analysis is only explicitly referenced in 13 papers; specifically, 50% of the cases performed an uncertainty analysis of the results (eg. Bell et al., 2018), 30% used the Quality matrix approach, (eg. Notarnicola et al., 2017) and in the remaining 20% of the papers, expert reviews and data consistency analysis were conducted (eg. lo Giudice et al., 2013). Paying attention to the data on the role of plant protection products, only 50% of the studies considered the use of estimation models or assumptions regarding the impact of plant protection products on the environment. The most widely used approach is that of Ecoinvent, which considers 100% of active substances accumulated in the soil system (eg. Ramos et al., 2016). In relation to the environmental impacts generated by the use of fertilizers, only 25 studies explicitly refer to estimation models (eg. Alishah et al., 2019; Nicolò et al., 2018), among which the most used are those proposed by the (IPCC, 2006), (Brentrup et al., 2000) and those proposed by (Nemecek et al., 2007). Only one study attests to the use of models for estimating the soil carbon stock, while only in three cases can the application of models for assessing the nutrient balance be considered. Relative to the research record identified as grey literature (Montanaro et al., 2017), a functional Mass Unit (1t of product) was used and no allocation or cut-off criteria were applied. The study mainly uses

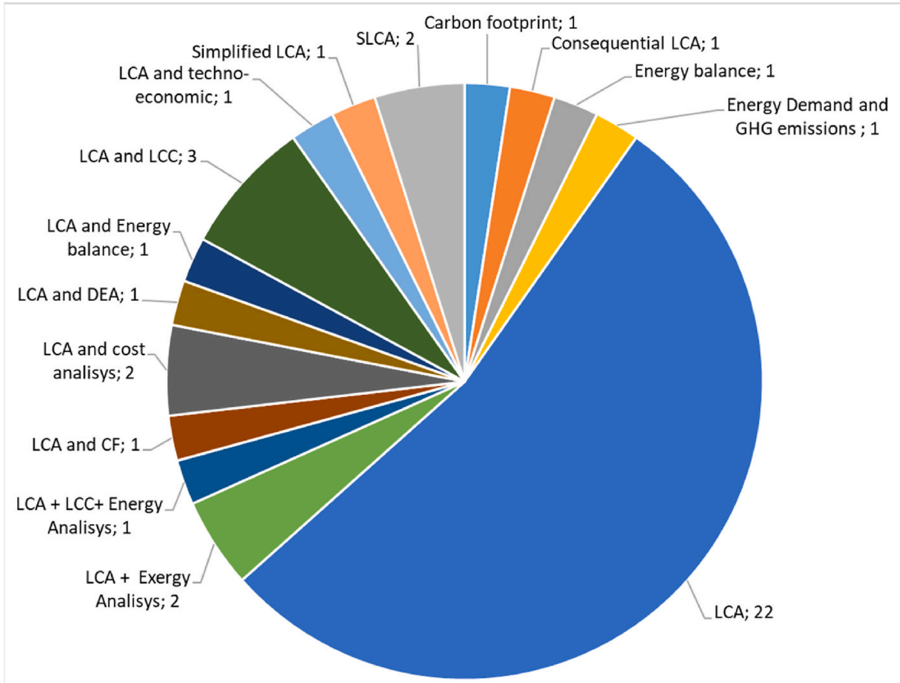

Fig. 3. Distribution of papers per methodology applied.

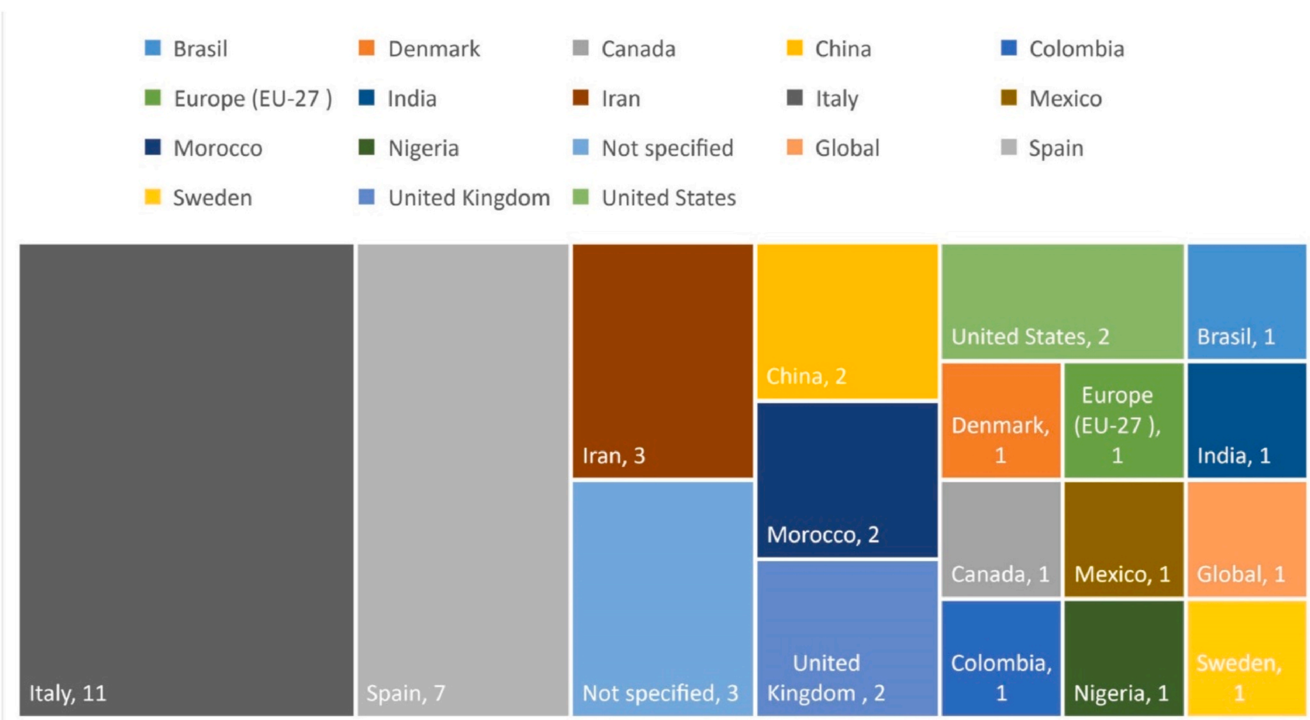

Fig. 4. Geographical boundaries of reviewed papers.

primary data for foreground processes, while the Ecoinvent database version 3.1 was used for background processes. There are no details on the impact of plant protection products and emissions from fertiliser use.

3.3. Allocation criteria, inventory analysis and impact assessment

The analysis of the selected bibliography, with reference to the allocation criteria, shows that in 22 papers there is no reference at all while the remaining 19 state that they have used an economic or mass allocation system (eg. Frankowska et al., 2019). Only one study, where the consequential approach is applied, refers to an expansion of the system (Negro et al., 2017).

The second step in the framework of an LCA study is the inventory analysis. In this regard, an analysis was also carried out with respect to the supplementary material published and it was found that only 29 of the 41 articles reported inventory data specific to the production processes of the citrus fruit chain (e.g. Mostashari-Rad et al., 2020). The third step is impact assessment, which was developed through the analysis of the Impact Assessment methods used, the impact assessment steps conducted, and the impact indicators considered. Among the most widely used Impact Assessment methods is the Re.Ci.Pe. method, which in its various revisions was used as the main method in 12 papers (eg. Zhang et al., 2018a), followed by the CML method which in its "2001, baseline and IA" versions was found in 9 papers (eg. Beltrán-Esteve et al., 2017). Three studies only used the ILCD method (eg. Garcia-Garcia et al., 2019), while the remaining part used either single impact indicators (mainly global warming potential and cumulative energy demand) or mixes of indicators borrowed from different methods sometimes not specified (eg. Ramos et al., 2016). The most frequently used impact category is Global Warming Potential, used in 36 articles (eg. Cacace et al., 2020), followed by Resource Use, Acidification Potential (eg. Alishah et al., 2019) (22 articles) and Ozone Layer Reduction (eg. Durkin et al., 2019) (19 articles). Other frequently used indicators were Eutrophication of Fresh and Marine Waters, Human, Water and Soil Toxicity, Land Use and Water Resources (Fig. 5).

All studies covered the classification and characterisation phase of the impacts, while only 8 of them also considered the optional impact assessment phases: 6 studies arrived at the weighting (eg. Mostashar-i-Rad et al., 2021) of the impacts while 2 ended with normalisation (Arzoumanidis et al., 2017; Notarnicola et al., 2017).

In Montanaro et al. (2017), there is a detailed inventory of primary and secondary data related to each phase of citrus orchard management. The assessment of impacts was conducted through the use of 5 impact categories, Climate change, Acidification, Ecotoxicity, Eutrophication, Water Scarcity, borrowed respectively from IPCC 2013 Global Warming potential, CLM 2001, Usetox, Re.Ci.Pe and Pfister methods. The impact categories used are consistent with the analysis of the SCOPUS and WOS indexed papers.

3.4. Summary of findings

The analysis of the results showed that among the 12 papers comparing different production systems, in 11 of them the conventional production system had the greatest impact (e.g. Beltrán-Esteve et al., 2017) and in only one of them the organic system (de Luca et al., 2015). Among the life cycle phases considered in the papers analysed, in those that included agricultural production it was always the phase with the greatest impact (eg. Nicoló et al., 2015), followed by the distribution phase in agreement with the results of studies that analysed the entire life cycle (lo Giudice et al., 2013). The inputs that most represent an environmental hotspot are generally fertilisers and fuels (eg. Ribal et al., 2017). Only 9 out of 41 papers included a sensitivity analysis of the results (eg. Zhang et al., 2018b), while in most articles the interpretation step was performed through critical discussion of the results obtained. In Montanari et al. (Montanaro et al., 2017) the most impactful phase of the life cycle of the orchards studied was found to be the full production phase; however, there are no details regarding the most impactful cultivation operation and input.

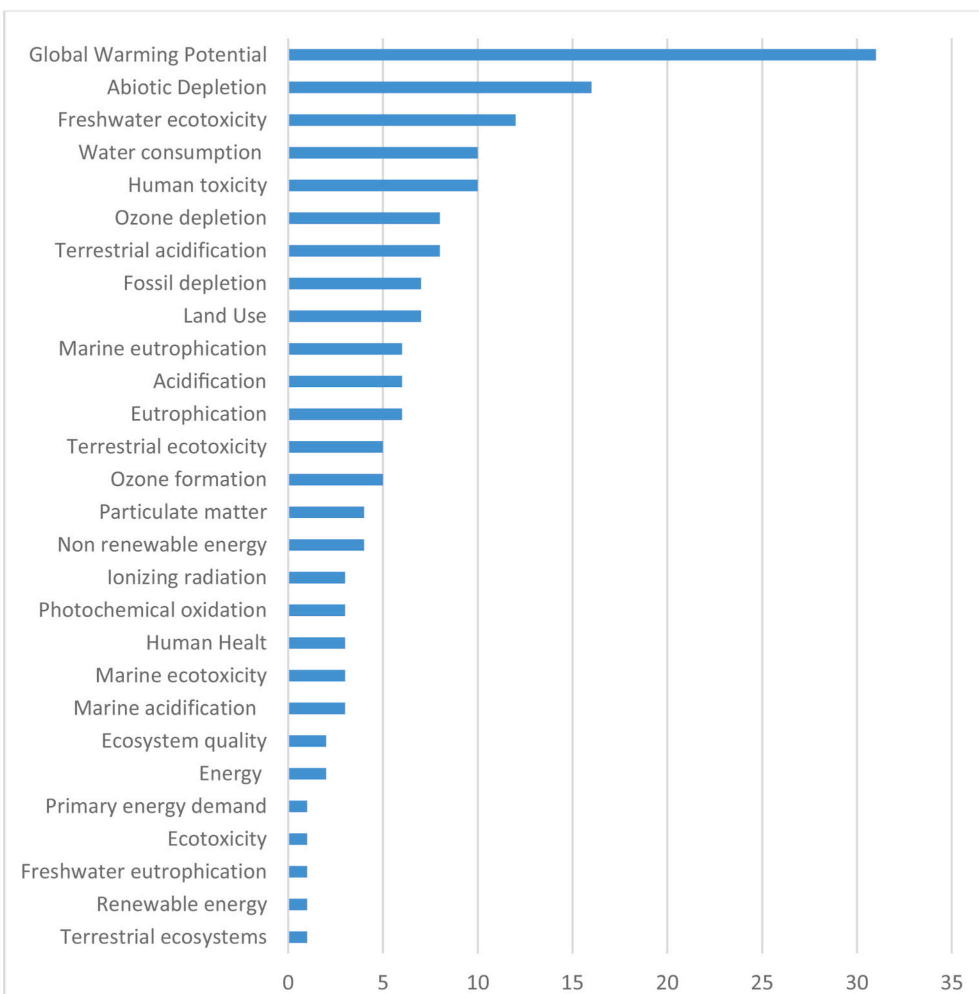

Fig. 5. Impact category distribution.

3.5. What tips are there for an LCA application to the citrus sector?

Generally speaking, it is not possible to provide any predefined recipe for any type of life cycle analysis; however, it is possible to draw some hints for scholars approaching the task of conducting a life cycle analysis of citrus.

The most critical phase is certainly the agricultural production phase. At this stage, both the species of citrus grown and the place of production make a difference in terms of production yields, cultivation techniques, but also product quality. For example, we go from the average production for lemons of 25–30 tons per hectare to the production of Limone "Femminello" in Sicily that can reach even 50 tons per hectare per year, thanks to the "forcing" technique that allows up to 4 blooms.

Starting from the function being studied and therefore from the definition of the functional unit, a first clarification must be made. If the function to be analysed is the productive function, then, clearly, the most suitable functional unit is the mass unit. Considering that generally agricultural production and conditioning or industrial production are practiced by different companies and in completely different production contexts, for agricultural production, it is always advisable to use a mass unit (e.g., 1 kg of product) as the functional unit. This will make it easy to compare products obtained by different techniques but also to use inventory data or impact profiles, as inputs for the next steps, in accordance with a "Modular" life cycle approach.

However, we know that, in general, areas suitable for citrus cultivation allow the cultivation of almost any species. The farmer may want to evaluate different investment alternatives also from an environmental point of view, and, in this case, the evaluation per unit area (e.g., 1 ha of cultivation) would be more suitable. This is because, as mentioned above, different types of citrus produce differently depending both on the area and on the species. For example, in Calabria, a hectare of Clementine produces about 30 tons while a hectare of Bergamot, under identical conditions, produces on average 18–22 tons. These are completely different products that have only the systematic genus in common. In this case, an LCA analysis with FU 1 ha combined with an LCC-type economic analysis can provide information to the entrepreneur or public decision-maker to evaluate more sustainable land management alternatives.

Regarding the system boundaries, of course, the issue is tricky and depends greatly on the availability of data. In general, we can consider the citrus supply chain as composed of deeply different production processes, so a modular approach might be the right choice. In this case, even a "Cradle to Grave" study could "compose" of different modules such as one related to agricultural production, from cradle to gate, which will represent an input for the next module of industrial processing, from gate to gate, which could, in turn, represent the input for the bottling and distribution phase, from gate to grave. In general, it appears to be very complex to carry out a comprehensive study, especially if it is based entirely on the use of primary data, while it is much easier if secondary data are considered for agricultural production or processing, in accordance with what was explained earlier. It should be highlighted that almost none of the studies analysed considers the nursery stage, while it would be important to model this stage as well since today's nursery production of citrus plants must meet phytosanitary standards (virus-free) that can make the plant propagation process very impactful.

In terms of data quality, it would be advisable to always use primary data at least for the agricultural cultivation part, precisely because of the great heterogeneity in production techniques and production results that can be found among different production areas and different types of citrus. The lack in commercial databases such as Ecoinvent, Agrifootprint, etc., of specific data on the different citrus production realities often forces this choice, while the existence of site-specific and species-specific datasets would allow even for the agricultural phase the use of secondary data without compromising the quality of the results.

Regarding the use of allocation approaches, this almost exclusively concerns the product intended for industry, where, in addition to juice, essential oils, and also other derivatives such as pectins, citric acid, etc. are extracted. Generally, an economic allocation approach is used, which is easier to apply; however, as suggested by ISO 14040, it would be preferable to use a system expansion approach, especially in light of new by-product valorisation technologies that considerably change the composition of the revenue derived from the various products and by-products of the citrus industry.

An LCA study of products in the citrus sector should consider a fairly broad set of impact categories, precisely because of the complexity of the supply chain. While the agricultural phase is characterized by emissions from the use of agricultural machinery, fertilizers, and pesticides, as well as very high water consumption (irrigation volumes often exceed 6000 m^3 of water per hectare per year), in the industrial phase very high amounts of electricity are consumed, large volumes of fossil fuels are used for the pasteurization and concentration stages, and a very high volume of wastewater must be treated.

Limiting an LCA study to a carbon footprint assessment alone, therefore, seems reductive, and more complex Impact Assessment methods such as CML, Recipe, Impact, etc., should be preferred. Interpretation of the results would always need to be carried out, especially by performing uncertainty assessments, because of the different quality of data from different links in the supply chain.

4. Conclusions

The objective of this paper was to evaluate, through a systematic literature analysis of the last 10 years, the state of the art of the implementation of the LCA approach to the citrus fruit supply chain. The review follows the STARR-LCA checklist approach and includes an analysis of 42 relevant articles from databases like Scopus, Web of Science, and Google Scholar.

The papers analysed are characterized by different objectives among which the most common is to assess the environmental impact of specific citrus products or their cultivation. The assessment of waste management scenarios linked to citrus industry represents a hot topic internationally, especially given the growing interest in designing circular economy strategies. With inventory data specific to the treatment of waste from the citrus industry, these papers can provide practitioners with a good source of secondary data, useful for supplementing the life cycle models they are studying. It was found that advancing the methodology is also a priority for the scientific community, and the papers analysed can provide useful insights for making decisions regarding citrus life cycle analyses.

The great complexity of the supply chain also emerges from the tendency to limit the boundaries of the system according to a cradle-to-gate approach. The choice to limit system boundaries is almost always dictated by the difficulty of finding specific inventory data for the distribution, consumption, and disposal stages, so this review can be a kind of repository where LCA experts can find the references they seek to complete their life cycle models.

Most of the studies focused on Italian productions, which demonstrates the great relevance of the sector for the Italian agro-economy, however, for researchers, the opportunity to access information related to the major production and consumption areas of citrus products is of great importance. This can serve as a reference point for comparative studies, a benchmark for identifying environmental best practices in the industry, and a data source for modeling the actual market mix of fresh or processed citrus fruits. In this regard, it emerges how the study of literature can be a good support for the LCA practitioner given that about 75% of the studies report useful inventory data.

Among the life cycle phases considered, agricultural production was consistently identified as the phase with the greatest impact, and in particular if is related to conventional production, that often had the greatest impact, primarily due to factors such as fertilizer and fuel use. If this is considered along with some methodological aspects, important insights for stakeholders may emerge. For example, if we take into consideration that the most frequently used functional units are the mass of product and the unit of area, we can say that the results can be supportive for the informed consumer who can direct his or her purchase toward organic products that generally have lower impacts, but also for the public decision maker who, through the results referred to the unit of area, can plan the most appropriate policies for the protection of the land.

It was also confirmed that Global Warming is one of the most strongly perceived issues and is the most widely used indicator of environmental impact (around 90%) along with Resource Depletion and Acidification.

In summary, this systematic review provides valuable insights into the state of LCA application in the citrus production chain and also points to areas of potential improvement and future research directions in LCA studies related to citrus production.

CRediT authorship contribution statement

Giacomo Falcone: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Software; Supervision; Validation; Visualization; Roles/Writing - original draft; Writing - review & editing; **Antonio Fazari:** Data curation; Investigation; Methodology; Software; Writing - review & editing; **Gregorio Vono:** Data curation; Formal analysis; Investigation; Methodology; Software; Roles/Writing - original draft; Writing - review & editing; **Giovanni Gulisano:** Conceptualization; Methodology; Supervision; Validation; Visualization Writing - review & editing; **Alfio Strano:** Funding acquisition; Resources; Conceptualization; Methodology; Project administration; Supervision; Validation; Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This article is part of the outcomes of the research project “Promoting Agri-Food Sustainability: development of an Italian LCI Database of Agri-Food Products (ILCIDAF)” (PRIN – Progetti di Ricerca di Interesse Nazionale 2017- Prot. 2017EC9WF2, settore ERC SH2, Linea C – financed by the Ministry of Education, University and Research).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cesys.2023.100156.

References

Aguilera, E., Guzmán, G., Alonso, A., 2015. Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. Agron. Sustain. Dev. 35, 725–737. https://doi.org/10.1007/s13593-014-0265-y.
Alishah, A., Motevali, A., Tabatabaeekoloor, R., Hashemi, S.J., 2019. Multiyear life energy and life cycle assessment of orange production in Iran. Environ. Sci. Pollut. Control Ser. 26, 32432–32445. https://doi.org/10.1007/s11356-019-06344-y.
Arzoumanidis, I., Salomone, R., Petti, L., Mondello, G., Raggi, A., 2017. Is there a simplified LCA tool suitable for the agri-food industry? An assessment of selected tools. J. Clean. Prod. 149, 406–425. https://doi.org/10.1016/j.jclepro.2017.02.059.
Basset-Mens, C., Vannière, H., Grasselly, D., Heitz, H., Braun, A., Payen, S., Koch, P., Biard, Y., 2016. Environmental impacts of imported and locally grown fruits for the French market: a cradle-to-farm-gate LCA study. Fruits 71, 93–104. https://doi.org/10.1051/fruits/2015050.
Bell, E.M., Stokes-Draut, J.R., Horvath, A., 2018. Environmental evaluation of high-value agricultural produce with diverse water sources: case study from Southern California. Environ. Res. Lett. 13, 025007 https://doi.org/10.1088/1748-9326/aaa49a.
Beltrán-Esteve, M., Reig-Martínez, E., Estruch-Guitart, V., 2017. Assessing eco-efficiency: a metafrontier directional distance function approach using life cycle analysis. Environ. Impact Assess. Rev. 63, 116–127. https://doi.org/10.1016/j.eiar.2017.01.001.
Bessou, C., Basset-Mens, C., Latunussa, C., Vélu, A., Heitz, H., Vannière, H., Caliman, J.-P., 2016. Partial modelling of the perennial crop cycle misleads LCA results in two contrasted case studies. Int. J. Life Cycle Assess. 21, 297–310. https://doi.org/10.1007/s11367-016-1030-z.
Brentrup, F., Küsters, J., Lammel, J., Kuhlmann, H., 2000. Methods to estimate on-field nitrogen emissions from crop production as an input to LCA studies in the agricultural sector. Int. J. Life Cycle Assess. 5, 349. https://doi.org/10.1007/BF02978670.
Cacace, F., Bottani, E., Rizzi, A., Vignali, G., 2020. Evaluation of the economic and environmental sustainability of high pressure processing of foods. Innovat. Food Sci. Emerg. Technol. 60, 102281 https://doi.org/10.1016/j.ifset.2019.102281.
Durkin, A., Taptygin, I., Kong, Q., Gunam Resul, M.F.M., Rehman, A., Fernández, A.M.L., Harvey, A.P., Shah, N., Guo, M., 2019. Scale-up and sustainability evaluation of biopolymer production from citrus waste offering carbon capture and utilisation pathway. Chemist 8, 668–688. https://doi.org/10.1002/open.201900015.
Dwivedi, P., Spreen, T., Goodrich-Schneider, R., 2012. Global warming impact of Florida’s Not-From-Concentrate (NFC) orange juice. Agric. Syst. 108, 104–111. https://doi.org/10.1016/j.agsy.2012.01.006.
Eriksson, M., Spångberg, J., 2017. Carbon footprint and energy use of food waste management options for fresh fruit and vegetables from supermarkets. Waste Manag. 60, 786–799. https://doi.org/10.1016/j.wasman.2017.01.008.
Falcone, G., Iofrida, N., Stillitano, T., de Luca, A.I., 2020a. Impacts of food and diets’ life cycle: a brief review. Curr Opin Environ Sci Health 13, 75–79. https://doi.org/10.1016/j.coesh.2019.12.002.
Falcone, G., Stillitano, T., de Luca, A.I., di Vita, G., Iofrida, N., Strano, A., Gulisano, G., Pecorino, B., D’Amico, M., 2020b. Energetic and economic analyses for agricultural management models: the Calabria PGI clementine case study. Energies 13, 1289. https://doi.org/10.3390/en13051289.
Faostat, 2021. Citrus Fruit Statistical Compendium 2020. Rome.
Faostat, 2022. Data on Crops and Livestock Products. https://www.Fao.Org/Faostat/En/#data/QCL.
Frankowska, A., Jeswani, H.K., Azapagic, A., 2019. Life cycle environmental impacts of fruits consumption in the UK. J. Environ. Manag. 248, 109111 https://doi.org/10.1016/j.jenvman.2019.06.012.
Garcia-Garcia, G., Rahimifard, S., Matharu, A.S., Dugmore, T.I.J., 2019. Life-cycle assessment of microwave-assisted pectin extraction at pilot scale. ACS Sustain. Chem. Eng. 7, 5167–5175. https://doi.org/10.1021/acssuschemeng.8b06052.
lo Giudice, A., Mbohwa, C., Clasadonte, M.T., Ingrao, C., 2013. Environmental assessment of the citrus fruit production in sicily using LCA. Ital. J. Food Sci. 203.
Gulisano, G., Strano, A., de Luca, A.I., Falcone, G., Iofrida, N., Stillitano, T., 2018. Evaluating the Environmental, Economic, and Social Sustainability of Agro-Food Systems through Life Cycle Approaches. https://doi.org/10.1016/B978-0-12-811935-8.00004-4.
Iofrida, N., de Luca, A.I., Silveri, F., Falcone, G., Stillitano, T., Gulisano, G., Strano, A., 2019. Psychosocial risk factors’ impact pathway for social life cycle assessment: an application to citrus life cycles in South Italy. Int. J. Life Cycle Assess. 24, 767–780. https://doi.org/10.1007/s11367-018-1482-4.
IPCC, 2006. N2O Emissions from Managed Soils and CO2 Emissions from Lime and Urea Application, 4 Ch11.
ISO, I.S.O., 2006a. Environmental Management — Life Cycle Assessment — Principles and Framework, 14040.
ISO, 2006b. ISO 14044 - Environmental Management — Life Cycle Assessment — Requirements and Guidelines.
Joglekar, S.N., Pathak, P.D., Mandavgane, S.A., Kulkarni, B.D., 2019. Process of fruit peel waste biorefinery: a case study of citrus waste biorefinery, its environmental impacts and recommendations. Environ. Sci. Pollut. Control Ser. 26, 34713–34722. https://doi.org/10.1007/s11356-019-04196-0.
Knudsen, M.T., Fonseca de Almeida, G., Langer, V., Santiago de Abreu, L., Halberg, N., 2011. Environmental assessment of organic juice imported to Denmark: a case study on oranges (Citrus sinensis) from Brazil. Organic Agriculture 1, 167–185. https://doi.org/10.1007/s13165-011-0014-3.
de Luca, A.I., Falcone, G., Stillitano, T., Strano, A., Gulisano, G., 2014. Sustainability assessment of quality-oriented citrus growing systems in Mediterranean area. Quality - Access to Success 15, 103–108. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84905381278&partnerID=40&md5=9793ba8313ef8d61e840d3784e429bab.
de Luca, A.I., Iofrida, N., Strano, A., Falcone, G., Gulisano, G., 2015. Social life cycle assessment and participatory approaches: a methodological proposal applied to citrus farming in Southern Italy. Integrated Environ. Assess. Manag. 11, 383–396. https://doi.org/10.1002/ieam.1611.
Maestre-Valero, J.F., Martin-Gorriz, B., Nicolas, E., Martinez-Mate, M.A., Martinez-Alvarez, V., 2018. Deficit irrigation with reclaimed water in a citrus orchard. Energy and greenhouse-gas emissions analysis. Agric. Syst. 159, 93–102. https://doi.org/10.1016/j.agsy.2017.10.017.
Martin-Gorriz, B., Gallego-Elvira, B., Martínez-Alvarez, V., Maestre-Valero, J.F., 2020. Life cycle assessment of fruit and vegetable production in the Region of Murcia

(south-east Spain) and evaluation of impact mitigation practices. J. Clean. Prod. 265, 121656 https://doi.org/10.1016/j.jclepro.2020.121656.

Martinez-Hernandez, E., Magdaleno Molina, M., Melgarejo Flores, L.A., Ruiz, MaE. Palmerín, Zermeño EguiaLis, J.A., Rosas Molina, A., Aburto, J., Amezcua-Allieri, M. A., 2019. Energy-water nexus strategies for the energetic valorization of orange peels based on techno-economic and environmental impact assessment. Food Bioprod. Process. 117, 380–387. https://doi.org/10.1016/j.fbp.2019.08.002.

Montanaro, G., Dichio, B., Berloco, T., Xiloyannis, C., 2017. Life Cycle Assessment (LCA) and Biomass Sampling of 5 Tree-Crops Categories (Olive, Citrus, Almond, Peach and Apple) within the Framework of Life ClimaTree Project (LIFE14CCM/GR/000635) - A Novel Approach for Accounting & Monitoring Carbon Sequestration of Tree Crops and Their Potential as Carbon Sink Areas".

Mostashari-Rad, F., Ghasemi-Mobtaker, H., Taki, M., Ghahderijani, M., Saber, Z., Chau, K.-W., Nabavi-Pelesaraei, A., 2020. Data supporting midpoint-weighting life cycle assessment and energy forms of cumulative exergy demand for horticultural crops. Data Brief 33, 106490. https://doi.org/10.1016/j.dib.2020.106490.

Mostashari-Rad, F., Ghasemi-Mobtaker, H., Taki, M., Ghahderijani, M., Kaab, A., Chau, K., Nabavi-Pelesaraei, A., 2021. Exergoenvironmental damages assessment of horticultural crops using ReCiPe2016 and cumulative exergy demand frameworks. J. Clean. Prod. 278, 123788 https://doi.org/10.1016/j.jclepro.2020.123788.

Negro, V., Ruggeri, B., Fino, D., Tonini, D., 2017. Life cycle assessment of orange peel waste management. Resour. Conserv. Recycl. 127, 148–158. https://doi.org/10.1016/j.resconrec.2017.08.014.

Nemecek, T., Kägi, T., Dübendorf, Z., 2007. Swiss Centre for Life Cycle Inventories A Joint Initiative of the ETH Domain and Swiss Federal Offices Life Cycle Inventories of Agricultural Production Systems Data v2.0, 2007. www.art.admin.ch.

Nicoló, B.F., de Salvo, M.C., Ramírez-Sanz, C., Estruch, A.v., Sanjuán, N., Falcone, G., Strano, A., 2015. Environmental Sustainability of the Clementine Production Systems in Italy and Spain:. An Approach Based on Life Cycle Assessment, pp. 173–184. https://doi.org/10.2495/ECO150161.

Nicolo, B.F., de Luca, A.I., Stillitano, T., Iofrida, N., Falcone, G., Gulisano, G., 2017. Environmental and economic sustainability assessment of navel oranges from the cultivation to the packinghouse according to environmental product declarations system. Quality - Access to Success 18, 108–112. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85020667736&partnerID=40&md5=7938262d2273ad2c8ab09fd7164043ca.

Nicolò, B.F., de Salvo, M.C., Ramirez-Sanz, C., Estruch, V., Sanjuan, N., Falcone, G., Strano, A., 2018. Life cycle assessment applied to different citrus farming systems in Spain and Italy. Agroecology and Sustainable Food Systems 42, 1092–1105. https://doi.org/10.1080/21683565.2018.1490942.

Notarnicola, B., Salomone, R., Petti, L., Renzulli, P.A., Roma, R., Cerutti, A.K., 2015. Life Cycle Assessment in the Agri-Food Sector. Springer International Publishing. https://doi.org/10.1007/978-3-319-11940-3.

Notarnicola, B., Tassielli, G., Renzulli, P.A., Castellani, V., Sala, S., 2017. Environmental impacts of food consumption in Europe. J. Clean. Prod. 140, 753–765. https://doi.org/10.1016/j.jclepro.2016.06.080.

Ogunlade, C.A., Jekayinfa, S.O., Olaniran, J.A., Adebayo, A.O., 2020. Energy life-cycle assessment and economic analysis of sweet orange production in Nigeria. Agricultural Engineering International: CIGR Journal 22, 123. http://www.cigrjournal.org.

Ortiz, D.L., Batuecas, E., Orrego, C.E., Rodríguez, L.J., Camelin, E., Fino, D., 2020. Sustainable management of peel waste in the small-scale orange juice industries: a Colombian case study. J. Clean. Prod. 265, 121587 https://doi.org/10.1016/j.jclepro.2020.121587.

Pergola, M., D'Amico, M., Celano, G., Palese, A.M., Scuderi, A., di Vita, G., Pappalardo, G., Inglese, P., 2013. Sustainability evaluation of Sicily's lemon and orange production: an energy, economic and environmental analysis. J. Environ. Manag. 128, 674–682. https://doi.org/10.1016/j.jenvman.2013.06.007.

Ramos, S., Larrinaga, L., Albinarrate, U., Jungbluth, N., Ingolfsdottir, G.M., Yngvadottir, E., Landquist, B., Woodhouse, A., Olafsdottir, G., Esturo, A., Zufía, J., Perez-Villareal, B., 2016. SENSE tool: easy-to-use web-based tool to calculate food product environmental impact. Int. J. Life Cycle Assess. 21, 710–721. https://doi.org/10.1007/s11367-015-0980-x.

Ribal, J., Ramírez-Sanz, C., Estruch, V., Clemente, G., Sanjuán, N., 2017. Organic versus conventional citrus. Impact assessment and variability analysis in the Comunitat Valenciana (Spain). Int. J. Life Cycle Assess. 22, 571–586. https://doi.org/10.1007/s11367-016-1048-2.

Ribal, J., Estruch, V., Clemente, G., Fenollosa, M.L., Sanjuán, N., 2019. Assessing variability in carbon footprint throughout the food supply chain: a case study of Valencian oranges. Int. J. Life Cycle Assess. 24, 1515–1532. https://doi.org/10.1007/s11367-018-01580-9.

Stillitano, T., Spada, E., Iofrida, N., Falcone, G., de Luca, A.I., 2021. Sustainable agri-food processes and circular economy pathways in a life cycle perspective: state of the art of applicative research. Sustainability 13, 1–29. https://doi.org/10.3390/su13052472.

Strano, A., Falcone, G., Nicolò, B.F., Stillitano, T., de Luca, A.I., Nesci, F.S., Gulisano, G., 2017. Eco-profiles and economic performances of a high-value fruit crop in southern Italy: a case study of bergamot (Citrus bergamia Risso). Agroecology and Sustainable Food Systems 41, 1124–1145. https://doi.org/10.1080/21683565.2017.1357064.

Yan, M., Cheng, K., Yue, Q., Yan, Y., Rees, R.M., Pan, G., 2016. Farm and product carbon footprints of China's fruit production—life cycle inventory of representative orchards of five major fruits. Environ. Sci. Pollut. Control Ser. 23, 4681–4691. https://doi.org/10.1007/s11356-015-5670-5.

Yang, M., Long, Q., Li, W., Wang, Z., He, X., Wang, J., Wang, X., Xiong, H., Guo, C., Zhang, G., Luo, B., Qiu, J., Chen, X., Zhang, F., Shi, X., Zhang, Y., 2020. Mapping the environmental Cost of a typical citrus-producing county in China: hotspot and optimization. Sustainability 12, 1827. https://doi.org/10.3390/su12051827.

Zhang, D., del Rio-Chanona, E.A., Shah, N., 2018a. Life cycle assessments for biomass derived sustainable biopolymer & energy co-generation. Sustain. Prod. Consum. 15, 109–118. https://doi.org/10.1016/j.spc.2018.05.002.

Zhang, D., del Rio-Chanona, E.A., Wagner, J.L., Shah, N., 2018b. Life cycle assessments of bio-based sustainable polylimonene carbonate production processes. Sustain. Prod. Consum. 14, 152–160. https://doi.org/10.1016/j.spc.2018.03.001.

Zumsteg, J.M., Cooper, J.S., Noon, M.S., 2012. Systematic review checklist - a standardized technique for assessing and reporting reviews of life cycle assessment data. J. Ind. Ecol. 16 https://doi.org/10.1111/j.1530-9290.2012.00476.x. S12–S21.