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Life cycle cost analysis of agri-food products: A systematic review

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Abstract

Because of the increasing challenges the global food system is facing on a social, economic and environmental level, and the need to meet the United Nations Sustainable Development Goals (SDGs) by 2030, agri-food systems are increasingly required to become more sustainable. Life cycle tools, such as a life cycle assessment (LCA) and life cycle cost analysis (LCC) to evaluate the environmental and economic performance respectively, play an important role in sustainability research. Contrary to LCA, the LCC methodology is not standardized for agri-food products. This study aims to obtain insights into the use of LCC in the agri-food sector using a systematic review approach. Data related to the methodology and findings of life cycle cost analyses of agri-food products were extracted from 92 articles, covering a wide range of products (crops: 59, food/drinks: 22, other: 11) and purposes. Currently, there is no consensus about LCC type definitions and the definition of different types of system boundaries amongst researchers. Furthermore, these and other methodological choices are often not reported in the analyzed studies. The data collection itself can also differ across studies, especially with regards to the inclusion of different cost categories. It is important to include each cost category since all categories have been identified as a costs hotspot in our list of studies (inputs: 84%, labor: 62%, machinery: 27%, other: 39%). Standardizing the LCC methodology is recommended to ensure comparability and enhance the scientific impact of studies. Integrating LCC results with findings from other life cycle tools, as done in 29 studies, can further support decision-making. The most common methods for integrating results are eco-efficiency analysis and multi-criteria decision analysis methods. In conclusion, it is clear that LCC is a very valuable tool, as a method on its own or complemented by other life cycle tools.

Keywords: life cycle costing, economic sustainability, sustainability assessment, life cycle thinking, sustainable agri-food systems, systematic review

1. Introduction

There is a need for agri-food systems to become more sustainable on a social, economic and environmental level. Considering the population growth projections and consequently the increase in food demand, reaching sustainability will be even more challenging in the future Gladek et al. (2016; (Godfray et al., 2010). Poverty, inequality, hunger and malnutrition, resource scarcity, ecosystem degradation and climate change are the result of our unsustainable food system (FAO, 2014). To tackle these challenges and meet the United Nations Sustainable Development Goals (SDGs) by 2030, the transformation of the agri-food sector will be crucial (Djekic et al., 2021). Therefore, the ability to measure and compare the sustainability of different food and processing options is important (Darton, 2015). To assess sustainability, multiple tools have been developed, including life cycle tools, which seem to play an important role in sustainability research (Notarnicola et al., 2017; Sala et al., 2013a; Sala et al., 2013b). Life cycle assessment (LCA), for example, is a well-established method to assess environmental sustainability over the entire product's life cycle in a wide range of different sectors (Guinée et al., 2011). The LCA tool has been used extensively to assess the environmental sustainability of agricultural products, food products, food processing technologies, food waste and bioenergy (Gava et al., 2019; Notarnicola et al., 2017; Omolayo et al., 2021; Roos and Ahlgren, 2018; Silva and Sanjuán, 2019). Thereby, different impact categories are often distinguished, e.g. global warming potential, land use, acidification, eutrophication,… (Meier et al., 2015).

More recently, researchers have started to include economic sustainability in the life cycle thinking framework (Norris, 2001), using life cycle cost analysis (LCC), also known as life cycle costing. This tool can be used for decision-making or for identifying economic hotspots to potentially decrease the product's life cycle costs (Hunkeler et al., 2008). The Society of Environmental Toxicology and Chemistry (SETAC) distinguishes three different types of life cycle cost analyses: conventional LCC, environmental LCC and societal LCC (Hunkeler et al., 2008). In contrast to conventional LCC, where typically only the direct costs covered by one actor are taken into account, the environmental LCC considers all costs over the product's life cycle for one or more actors, including the costs of internalized or soon-to-be-internalized externalities (Hoogmartens et al., 2014; Hunkeler et al., 2008). Societal LCC takes all costs, including externalities, for all actors that are directly or indirectly affected by the production, into account (Hoogmartens et al., 2014; Hunkeler et al., 2008). Environmental LCC can be used in combination with LCA, if the same system boundaries and functional unit is used (Hunkeler et al., 2008; Kloepffer, 2008; Swarr et al., 2011). While the LCA methodology has been standardized and can be applied to any product (ISO, 2006a; ISO, 2006b), the LCC methodology has only been standardized for petroleum, gas, buildings and constructed assets (ISO, 2008; ISO 2021). Currently, there is no international standard available for the life cycle cost analysis of agricultural and food products. Recent reviews of life cycle costing of food waste management and life cycle costing in urban agriculture have found inconsistencies within the methodological aspects of LCC (De Menna et al., 2018; Peña and Rovira-Val, 2020). In conclusion, insights into the methodological framework for LCC in the agri-food sector are needed.

Even though the - rather standardized - use of LCA for agri-food systems still faces some challenges (e.g. comparability of studies, LCA does not capture all aspects necessary for sustainability,…) (Baldini et al., 2017; Notarnicola et al., 2017; Schau and Fet, 2008), it is well-established, unlike the use of LCC in agri-food systems. To address this gap, a systematic review of life cycle cost analyses of agri-food products will be conducted. This paper aims to identify the current issues related to the LCC methodology and to get a better understanding of the methodological framework of life cycle costing in the agri-food sector. Furthermore, methodological suggestions for future LCC studies will be formulated. To our knowledge, such a systematic review of life cycle cost analyses in the agri-food sector does not exist, except for the aforementioned reviews on two specific agri-food domains, i.e. food waste (De Menna et al., 2018) and urban agriculture (Peña and Rovira-Val, 2020). This systematic review will further differ from existing reviews in the fact that it (1) uses a different methodological approach (systematic) and (2) includes all studies conducting a life cycle cost analysis of food or agricultural products instead of focusing on food waste or urban agriculture only. The next section of the paper explains the methodology that is used for this systematic review. The third section focuses on the results and compares them to existing literature. Finally, the last section will contain the conclusions.

2. Material and methods

2.1. Article selection

The database Scopus and Web of Science were used to search for relevant articles in June 2022. The syntax that was used to search for relevant literature consisted of two parts. The first part of the syntax had to identify all life cycle costing studies and therefore consisted of LCC and all its synonyms: “Life Cycle Cost*” OR “LCC” OR “production cost* analysis” OR (economic AND (“life cycle sustainability assessment” OR LCSA)). The second part of the syntax had to identify all agri-food related studies, including beer and other beverages: food OR feed OR agri* OR agro* OR crop* OR farm* OR livestock OR beer OR beverage*. The word “beer” was added to the syntax to include a highly cited paper (Amienyo and Azapagic, 2016) that was found during a preliminary search to define the study’s scope. Since the aim of this systematic review is to get insights into the methodological framework of life cycle cost analysis in the agri-food sector, both parts of the syntax had to be present for an article to be selected. The search resulted in 1347 papers from Scopus and 1882 papers from Web of Science, which were later transferred into one database using EndNote software.

2.2. Article screening

To identify all relevant articles, specific inclusion criteria were used. All peer-reviewed articles conducting a life cycle cost analysis in the agri-food sector, either as an independent study, or in conjunction with a life cycle assessment, or as part of a life cycle sustainability assessment, were included. Furthermore, the article had to be written in English, accessible, the life cycle costing method had to be explicitly mentioned and the article had to cover the production of food, feed, bio-energy or other agricultural products. Articles published before 2000 were excluded. In addition, studies that focused exclusively on waste without including the agricultural or food production phase (e.g. production of biogas), were excluded. Review articles and articles that did not include a case study (e.g. articles focusing on methodology) were also excluded. The identification of all relevant studies was done by using a screening process based on the PRISMA flow diagram (Moher et al., 2009), as depicted in Fig. 1. Initially, all papers retrieved from Scopus and Web of science were transferred into one database using EndNote software, and duplicates were removed (819). Subsequently, articles were screened based on their titles, which led to the exclusion of 1935 articles because they did not consider the LCC of agri-food products. Next, 306 articles were excluded based on their abstracts, and 4 more papers were excluded based on the accessibility. The remaining 165 papers were screened in-depth. Based on the inclusion criteria, 73 papers were excluded during full paper screening (e.g. no case study, focus on food packaging, LCC not explicitly mentioned,…). As a result, 92 relevant papers were included for data extraction.

2.3. Data extraction

All relevant information was extracted from the papers by using data extraction sheets. Three extraction sheets were developed to gather information on methods, findings and quality. First, general information like authors, title, publication year, database, journal, country, and product type was extracted. Next, all relevant information regarding the LCC methodology was extracted. This included information on the goal of the LCC, functional unit, system boundaries, included stakeholders, data source, discount rate, sensitivity analysis, included costs, visual reporting, use of other economic parameters, use of other life cycle tools and whether results of these tools are integrated with LCC results. As for the data extraction sheet on findings, information on cost hotspots and main conclusions from LCC and other life cycle tools (e.g. LCA and social LCA) were gathered. A final data extraction sheet was developed to assess the quality of the selected studies. The yes/no questions in this sheet were based on existing critical appraisal checklists for economic evaluation from the Joanna Briggs Institute

(JBI) (Gomersall et al., 2015) and the Scottish Intercollegiate Guidelines Network (SIGN) (Sutherland et al., 2015).

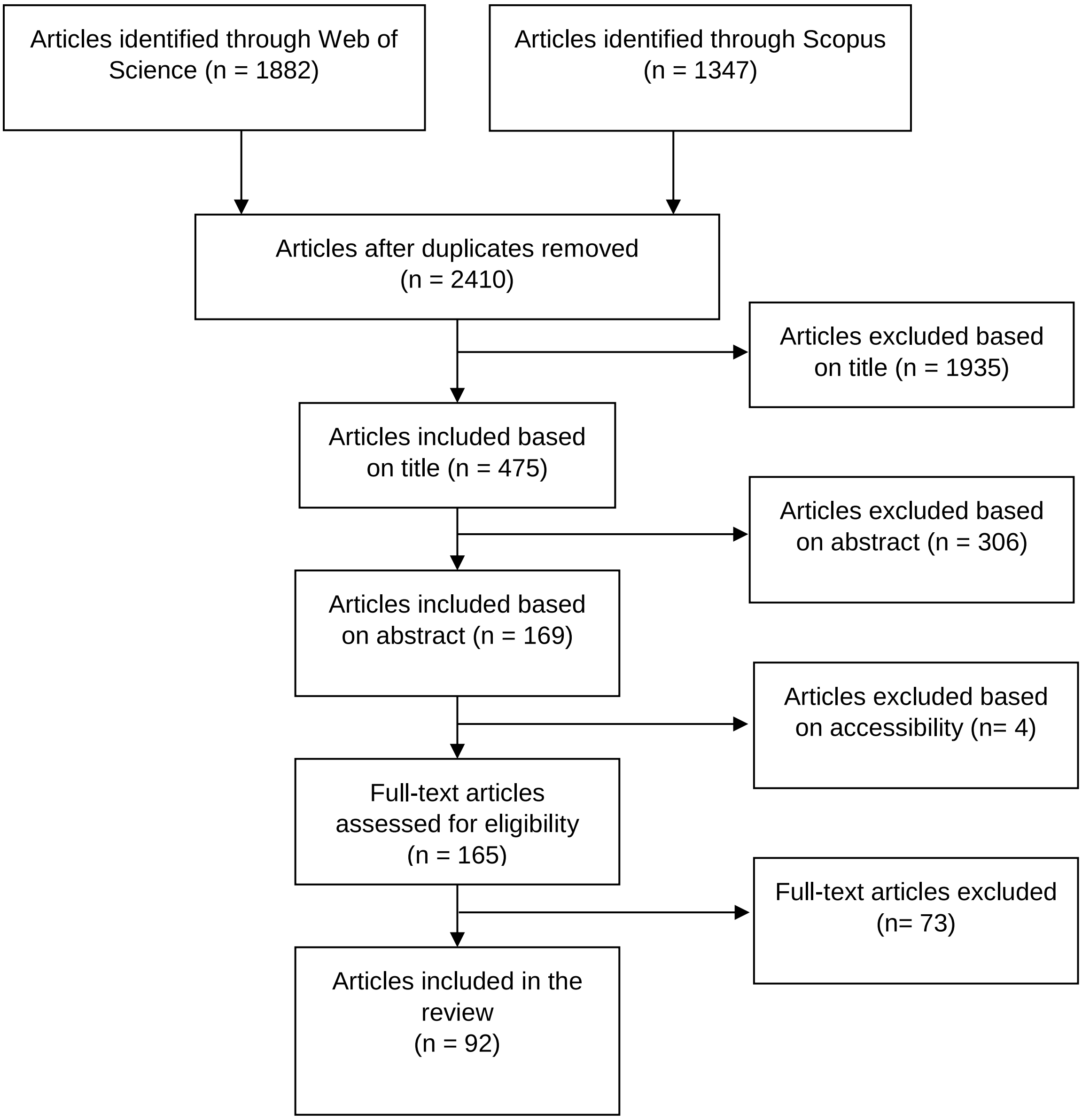

Fig. 1. Screening process, based on the PRISMA flow diagram (Moher et al., 2009), to identify all relevant studies.

3. Results and discussion

3.1. Study characteristics

In total, relevant data was extracted from 92 articles. The articles were published in a wide range of different journals, from journals focusing directly on life cycle assessment (e.g. 6 articles in the International Journal of Life Cycle Assessment) to journals with a broader scope like the Journal of Cleaner Production (20 articles), Sustainability (12 articles) and Science of the Total Environment (5 articles). The number of published LCC studies has increased significantly over the recent years. Only 9 LCC studies were published from 2008 (oldest studies in dataset)-2013. During the period 2014-2016 15 studies were published, while 26 studies were published from 2017-2019. During the last 2 years and a half (2020-2022) 42 LCC papers got published, showing the increased interest of the scientific community in life cycle thinking. Most studies (66) perform a life cycle cost analysis in Europe. Life cycle costing studies have been focusing mainly on Italian agri-food products (28 articles). After Italy, most LCC research has been conducted in the United Kingdom (7 articles). Most of the papers (59) deal with agricultural products, of which 30 articles focus on perennials, 22 on annual crops and 7 papers focus on both perennials and annuals. Regarding the product type, 19 papers focus on food products, 2 on beverages and 1 paper focuses on a food product and beverage. The remaining papers perform an LCC on livestock (8 studies) or other products (3 studies; investment in poultry shed, investment in beekeeping infrastructure, feed).

3.2. Methodological aspects

3.2.1. Goal and scope of life cycle costing studies

Most LCC studies (54 studies) compare 2 or more different production scenarios, for example, the organic versus conventional production of olives (Iofrida et al., 2020). Eight papers compare the life cycle costs of different products based on specific production scenarios, for example, the organic and conventional production of both oranges and lemons (Pergola et al., 2013). Fifteen papers focus on the comparison of the life cycle costs of different products like the study from Wagner et al. (2019b), in which biogas costs are compared to the costs of fossil fuel. Apart from this, 15 papers neither compare products nor production scenarios. Following these observations, it can be stated that life cycle costing can be used for different purposes, such as choosing between different options or evaluating the life cycle cost of 1 specific product.

The type of LCC is not mentioned in 61 papers (Fig. 2). In the studies that mention the type of LCC (31, one paper applies 2 different types of LCC), conventional LCC is most often referred to (21 papers), followed by environmental LCC (9 papers) and finally societal LCC (2 papers). For the societal LCC, the social cost of externalities, in this case from atmospheric pollutants (Blanc et al., 2019) and air, water, soil pollutants, indirect land use change and transport (Albizzati et al., 2021), were added to the conventional costs. The lack of studies including a societal life cycle cost analysis might be caused by the difficulties associated with conducting a societal LCC, such as the risk of double counting (when LCA is complemented by LCC, the costs of environmental externalities should not be included in the LCC) and methodological difficulties with regards to internalizing externalities (which externalities should be internalized?, how can externalities be internalized?, etc.) (Neugebauer et al., 2016). According to the Society of Environmental Toxicology and Chemistry (SETAC), environmental LCC takes the costs over the complete life cycle of a product for one or more actors, including the soon-to-be-internalized externalities, into account and is complemented by an LCA (Hunkeler et al., 2008). In contrast, a conventional LCC takes the costs over the product’s life cycle, excluding the end-of-life phase, for one actor into account and is not accompanied by an LCA (Hunkeler et al., 2008). The definition for conventional and environmental LCC, given by e.g. Hunkeler et al. (2008), is often not followed in the analyzed studies. For example, both types are often accompanied by a life cycle assessment (all articles using environmental LCC and 17 out of 21 articles for conventional LCC). As a result, there is no clear distinction between LCC types. This finding is in line with the results of the review paper from De Menna et al. (2018). Most papers conducting an environmental LCC take the consumption phase and end-of-life costs (cradle-to-grave) into account, except for Florindo et al.

(2017) and García-Herrero et al. (2022). On the contrary, papers conducting a conventional LCC do not consider the consumption phase and end-of-life costs (cradle-to-gate), except for Albizzati et al. (2021). In conclusion, there is a need for standardized definitions for the different LCC types, which researchers can follow when conducting an LCC.

Three papers do not explicitly mention a functional unit (Fig. 2) but calculate the total cost of a firm over the entire production facility's lifetime (Koričan et al., 2022; Le Feon et al., 2021; Strano et al., 2015). In the papers that express the life cycle costs per functional unit, mass (56 papers; e.g. costs per kg) and area (28 papers; e.g. costs per ha) are most often used (Fig. 2). Only 15 studies calculate the life cycle costs for more than one functional unit. The functional unit should be carefully chosen since the life cycle costs might differ significantly depending on the functional unit (e.g. yield impacts the life cycle costs per kg, while it does not impact the life cycle costs per ha) (Fenollosa et al., 2014; Tamburini et al., 2015), which is why the use of more than 1 functional unit might be recommended.

Surprisingly, the system boundaries used to conduct a life cycle cost analysis are often not explicitly mentioned (29 papers) (Fig. 2). For the studies that mention the system boundaries, a cradle-to-gate approach is most often used (38 papers), followed by a cradle-to-grave approach (17 papers) and some other approaches like for example a cradle-to-fork approach. The differences between these approaches are not always clearly defined in the studies. For example, a study claiming to include the whole life cycle of a product (cradle-to-grave), does not include the transformation, distribution and consumption phase (De Gennaro et al., 2012), in contrast to other studies. These discrepancies between studies make it more difficult to compare results. Some authors use approaches similar to cradle-to-gate and cradle-to-grave but name them differently, like cradle-to-use (Baquero et al., 2011), cradle-to-fork (Sanyé-Mengual et al., 2018), cradle-to-consumer (Sanyé-Mengual et al., 2015), cradle-to-retail (Verduna et al., 2020) and cradle-to-market (Zhen et al., 2020).

Finally, 63 studies consider only one actor (e.g. farmer or processor) in the value chain, as compared to 29 articles that consider multiple actors (e.g. farmer + processor, processor + consumer, farmer +

processor + consumer) for life cycle cost calculation (Fig. 2). The life cycle costs assigned to the cultivation phase of agri-food products are targeted in 52 studies. Besides the cultivation phase, the costs assigned to the processing phase (8 studies), distribution phase (1 study), consumption phase (2 studies) or a combination of multiple phases in the value chain (29 studies) are considered in the literature as well. The necessity of including multiple phases depends on the goal and focus of the study. No significant differences are observed for these methodological aspects when comparing older studies with studies that have been published more recently.

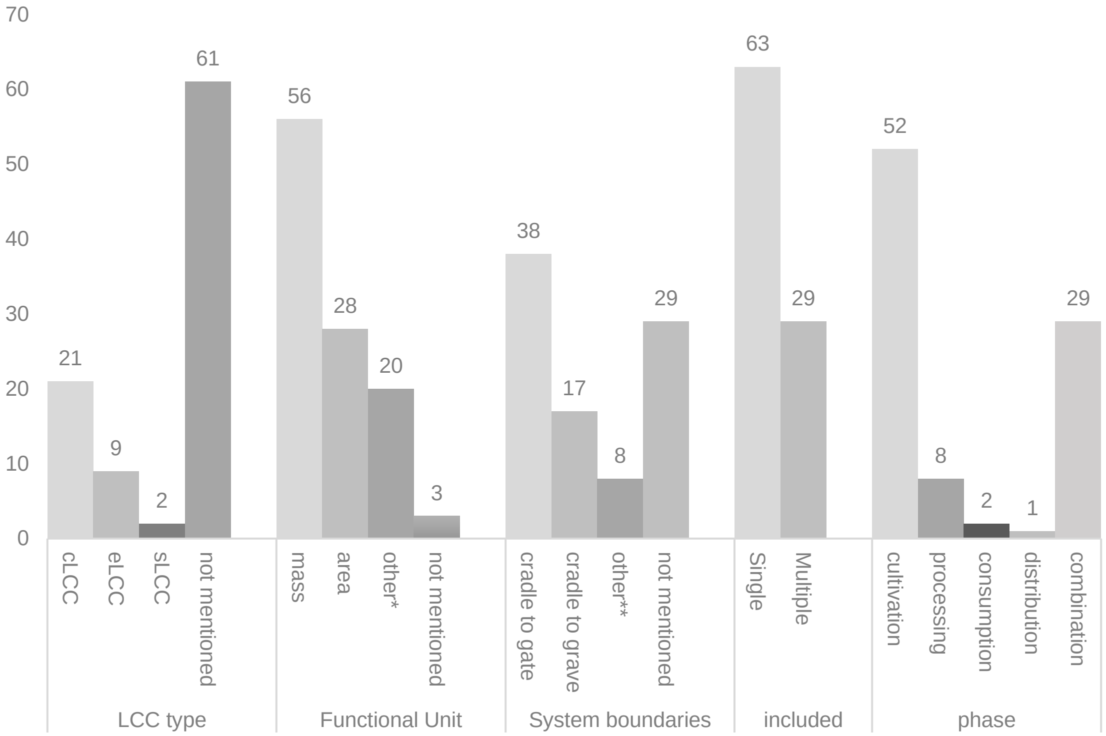

Fig. 2. Number of studies according to LCC type, functional unit, system boundaries, included number of stakeholders and included life cycle phase. *volume, 1 meal, annual consumption, energy, power needed for 1km of driving. **cradle-to-use, cradle-to-fork, cradle-to-consumer, cradle-to-market.

3.2.2. Life cycle costing data

Both primary (69 studies) and secondary (73 studies) data are used to calculate a product's life cycle cost (Fig. 3). Primary data is gathered directly from stakeholders, for example, the farmer or processor, while secondary data sources consist of life cycle inventory databases like Ecoinvent, which is used in most papers, agricultural databases and data from scientific papers. In more than half of the studies (50), primary data is collected and complemented by secondary data where necessary. Concerning the primary data, a wide variety of sample sizes was used to calculate life cycle costs, ranging from 1 to 213. The sampling method is not specified in most papers, except for the method in De Luca et al. (2014) (non-probability sampling), Jirapornvaree et al. (2021) (non-probability sampling), Li et al. (2021) (random sampling), Omran et al. (2021) (simple random sampling), Pergola et al. (2013) (stratified sampling) and Stillitano et al. (2016) (stratified sampling). If possible, the use of a larger sample size is more appropriate since it will give a better representation of the average life cycle cost. Additionally, data from multiple seasons/ years is preferred for a more representative average cost and to control for seasonal fluctuations in yield and external factors that influence the productivity (De Luca et al., 2014; De Luca et al., 2018b; Falcone et al., 2016). A similar number of studies consider multiple seasons or years (19 studies) and only one season or year (17), while in most papers (56) this is not mentioned or irrelevant (Fig. 3).

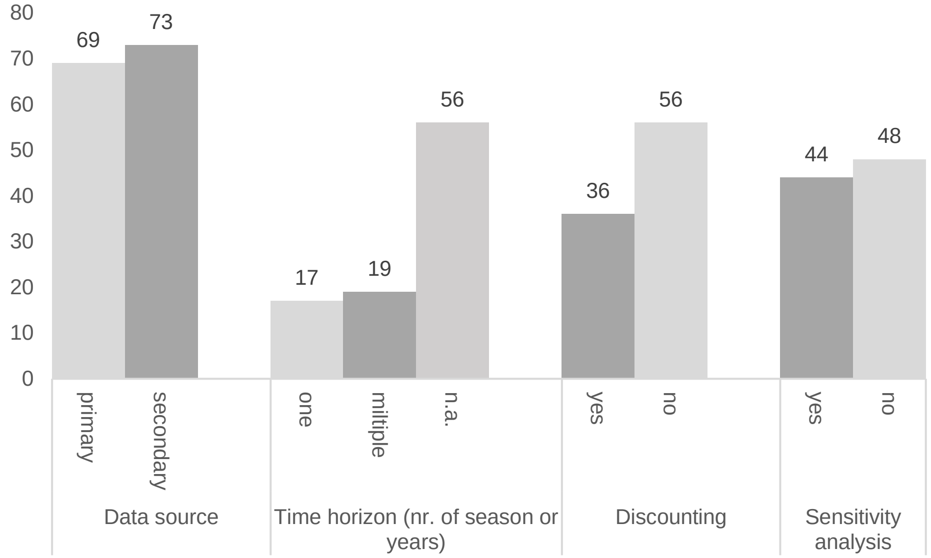

Fig. 3. Number of studies based on to the used data source, time horizon, application of discounting, and application of a sensitivity analysis.

Less than half of the studies discount future cash flows to deal with the time value of money (Fig. 3). The discount rate ranges from 1,12% to 12,5%. For a third of the studies, there is no explanation given for the choice of discount rate. In general, agricultural investments are considered as low risk, which is why a low discount rate is used (Mohamad et al., 2014; Stillitano et al., 2016). Higher discount rates are used if the investment risk is perceived to be higher, for example for urban plant factories (Liaros et al., 2016). The result of using a high discount rate is that the net present value will be lower. Discounting should only be used if future cash flows are expected, which is not the case for annual crops. Furthermore, papers focusing on food or beverage production without considering investment costs for machinery and equipment, did not apply discounting (e.g., Amienyo and Azapagic (2016) and Konstantas et al. (2019)). If investment costs are considered and cash flows are calculated for multiple years or the entire lifetime of a project, discounting is applied (e.g. in Strano et al. (2015)).

Almost half of the studies (44) conduct a sensitivity analysis to deal with uncertain data (Fig. 3). A sensitivity analysis can be done by manually varying certain parameters (e.g. yield, discount rate,… (Falcone et al., 2016; Kim et al., 2018)) or by statistically running Monte Carlo simulations (Canaj et al., 2021b; De Gennaro et al., 2012; Konstantas et al., 2019; Olba-Ziety et al., 2022; Roselli et al., 2020) to see the effect on the final life cycle cost of the product.

All LCC studies included the costs of inputs, for instance raw materials, water and fuel (Fig. 4). Most studies also include labor (72) and machinery (64) as costs (Fig. 4). In contrast, machinery is often not included in life cycle assessment studies due to the lack of data (Silva and Sanjuán, 2019). In some articles, it is not clear if labor and machinery are included because no details on the included costs are given (e.g. Rivera and Azapagic (2016)). Other costs related to, for example, taxes, insurance, services, interests, land capital, and food losses, are also included in most articles (67) (Fig. 4). No significant differences are observed for the inclusion of the different cost categories when comparing older studies with studies that have been published more recently. The cost of (some) externalities is only considered in 12 studies (Albizzati et al., 2021; Blanc et al., 2018; Blanc et al., 2019; Canaj et al., 2021a;

Canaj et al., 2021b; Dobon et al., 2011; Moosavi-Nezhad et al., 2022; Rahmah et al., 2022; Ribeiro et al., 2018; Ruviaro et al., 2020; Saber et al., 2020; Smith and Lal, 2022) (Fig. 4). Most of the papers (8) only include the societal/environmental cost of atmospheric pollutants since the costs for those have been quantified in previous studies and are more established (lower degree of uncertainty) than the costs of other environmental indicators (Yang et al., 2022) (e.g. emission costs validated by the US government (Smith and Lal, 2022)). The remaining papers (4) included more externalities in the LCC than only the atmospheric pollutants, for example water pollutants, soil pollutants, externalities of transport and land use change (Albizzati et al., 2021), all environmental indicators from the LCA (Canaj et al., 2021a; Canaj et al., 2022) and noise (Dobon et al., 2011). To calculate the costs of these externalities most studies multiplied LCA results with cost values from literature, while Blanc et al. (2018) and Blanc et al. (2019) used the value of a life year (VOLY) approach to calculate the costs of externalities to society. According to the review paper from Amadei et al. (2021) there is a lack of recent research regarding the monetary valuation of LCA results. The monetization of LCA results can be done by using different methodologies, e.g. observed preferences (market price), revealed preferences, stated preferences, budget constraint and abatement cost, each having its own strengths and weaknesses (Amadei et al., 2021; Arendt et al., 2020; Pizzol et al., 2015). The monetary values of LCA results vary a lot across different studies (Arendt et al., 2020), leading to difficulties when comparing results. If the LCC is complemented by an LCA and the costs of externalities are included, there is a risk of double-counting environmental or social indicators (Hunkeler et al., 2008), which should be avoided. There is no clear case of double-counting in the 12 studies including externalities. More details about the included cost types for each study can be found in Table 2. When comparing the included cost categories per product type, studies regarding the life cycle costs of perennial crops generally include most cost types. Each cost category is included in at least 72% of the studies. For studies focusing on annual crops and food products/beverages, each category is included in around 60-70% and 45-70% of the studies, respectively, except for the category “inputs”, which is included in all studies. The 8 studies concerning livestock include all cost types, except for the category “other”, which is only included in 6 studies. The remaining 3 studies, focusing on feed, the investment in a poultry shed and beekeeping, include most cost categories.

More than 65% of the studies consider revenues to calculate the profitability of the product, aside from the calculation of the life cycle cost of a particular product. Thirty-eight papers calculate 1 or more economic evaluation parameter(s). The net present value (NPV) is used in most cases (24), followed by the internal rate of return (IRR) (14). In some studies, other economic parameters like added value and payback period, are calculated.

3.2.3. Life cycle costing integrated with other life cycle tools

Out of 92 published studies reviewed in this systematic review, 72 studies concerning LCC also include other life cycle tools, like LCA (71) and social LCA (sLCA) (13). For these studies, LCC, LCA and sLCA are performed individually based on the same functional units and system boundaries. However, it is rather uncommon that researchers integrate the results from these assessments. Only 29 papers use an integrated approach to present LCA and LCC results together (Table 1). In this dataset, sLCA was never conducted before 2017, while almost half of the studies did a life cycle assessment. Around 20% of the studies before 2017 integrated the results from both assessments. More recently (from 2017 onwards), studies have increasingly conducted LCA (>80%) and sLCA (15-27%), and have started to integrate the results of multiple life cycle tools (around 30%). These results show that a more comprehensive sustainability assessment, focusing on the 3 pillars of sustainability, is starting to gain more attention from researchers.

Life cycle assessment is performed for different agri-food products to evaluate the ecological impacts of the product. The common goal of all the research is to find possible ways to reduce environmental and economic impacts and highlight further optimization potential. Many different methods can be used to integrate LCC and LCA results. Eco-efficiency analysis, which combines the economic index with environmental burden indices (World Business Council for Sustainable Development, 2006) (Eco-efficiency = (Product value)/(Environmental impact)), and multi-criteria decision-making methods are mostly used within the list of studies (Table 1). To calculate the eco-efficiency different indicators are used for the economic (e.g. LCC, profit) and environmental (e.g. GWP, multiple indicators) part of the formula. Multi-criteria decision-making methods in combination with life cycle thinking methods have been identified as valuable in the review paper from De Luca et al. (2017). It can be concluded that the integration of economic and environmental results is still limited but can be very valuable from a research point of view but also for policy-makers and industry for decision-making.

Table 1. References that integrate LCC and LCA results, the methodology used for integrating and the visual reporting style for results.

Reference	**Methodology for integrated results**	**Visual reporting style**
Valente et al. (2020); Zira et al. (2021)	The sustainability framework/ LCSA framework	Radar chart
Baum and Bienkowski (2020); Canaj et al. (2021b); Sanyé-Mengual et al. (2018); Zhen et al. (2020); Laso et al. (2018); Konstantas et al. (2019); Konstantas et al. (2020); Pari et al. (2022); Pari et al. (2020); Pexas et al. (2021)	Eco-efficiency analysis	Scatter plots; Bar chart; Table; Heat map
Albizzati et al. (2021); Chen and Holden (2018)	Multi-criteria analysis – No specific method mentioned	Radar chart
De Luca et al. (2018a)	Multi-criteria analysis - Analytic Hierarchy Process (AHP)	Pie chart, Bar chart
Dobon et al. (2011)	Sustainability analysis (LCA + LCC + Willingness to Pay)	Table
Ekener et al. (2018)	Multi-criteria analysis – Multi-Attribute Value Theory	Table; bar chart
Falcone et al. (2016); Florindo et al. (2020)	Multi-criteria analysis – VIKOR method	Scale chart using Composite Index of Sustainability; Table
Le Feon et al. (2021)	Multi-criteria analysis – DEXi method	Table, radar chart
Ribeiro et al. (2018)	Social Return on Investment (SROI)	Color scale
Rivera and Azapagic (2016)	Quantitative approach	A combined heat map
Tamburini et al. (2015); Canaj et al. (2021a); Canaj et al. (2022)	Semi-quantitative approach	Table; bar chart
Wohner et al. (2020)	Technique for Order by Similarity to Ideal Solution (TOPSIS)	Bar chart and color matrix
Zortea et al. (2018)	Dashboard of Sustainability (DoS)	Windrose diagram with sustainability indicators

Brandão et al. (2010); Omran et al. (2021)	No specific name	Line chart; Bar chart

3.3. Critical appraisal

All studies have a clear research objective, with the majority (90) also having a clear economic importance. For 19 studies it is not entirely clear which costs are included and which are not. For those who clearly described the included costs, 57 studies included all cost categories, while 16 studies did not. Discounting has been applied in 37 studies. Fifty of the remaining studies did not apply discounting because there were no future cash flows (n.a. in Table 1 in appendix), while 5 studies did not consider the time value of money (no in Table 1 in appendix). Almost half (44) of the studies conducted a sensitivity analysis. Finally, most of the studies (77) clearly describe the economic results. The quality aspect with the worst score is the sensitivity analysis, while the other aspects score relatively well.

Most studies (59) score at least 80% on the checklist for quality evaluation, which corresponds to 5 stars (Table 1 in appendix). Twenty studies score between 60 and 80% (4 stars). Twelve studies get 3 stars (40-60%) and finally only 1 study scores 2 stars (20-40%). It can be concluded that most studies have a high quality. However, some methodological aspects, discussed in section 3.2., are also important indicators for the quality of LCC studies (e.g. clear LCC type and clear system boundaries). If these methodological aspects would have been included for quality appraisal, the quality of many papers would have been lower. When conducting a life cycle costing study, all these aspects should be considered to develop a high-quality study.

3.4. Reporting and findings

Life cycle costing is applied to a wide range of different agri-food products. For some studies, the goal is to identify cost hotspots and to explore if the production is economically profitable, while other studies compare products or production scenarios. Findings are most often visually reported by the use of tables (59 studies), followed by column or bar charts (39). Other charts for visually representing the findings are also used, for example, line charts, pie charts and scatter plots. In almost 30% of the studies, a combination of different reporting methods is used.

3.4.1. Economic hotspots

Out of 92 studies, 55 identified the economic hotspots (most significant costs) for specific agri-food products, while the remaining studies did not give any details or used a different cost typology (e.g. total cost for each activity/ stakeholder instead of dividing costs into the categories “inputs”, “labor”, “machinery” and “other”). Out of the 55 studies that identified hotspots, inputs, like raw materials, fertilizer, fuel, etc., were identified as a cost driver in 46 studies (84%; Fig. 4). Labor and machinery were identified as main cost drivers in 26 and 11 studies, respectively. Finally, 15 studies identified other main hotspots like for example costs related to land and end-of-life costs (Florindo et al., 2017; Lask et al., 2020; Ruviaro et al., 2020; Stillitano et al., 2019; Strano et al., 2017; Zhen et al., 2020; Zortea et al., 2018). If labor, machinery and other costs are considered in the study and economic hotspots are identified, they are cost drivers in 62% (26 out of 42 studies), 27% (11 out of 41 studies) and 39% (15 out of 38 studies) of the studies, respectively. Considering this result, it is clear that each cost category should be considered in future life cycle costing studies of agri-food products.

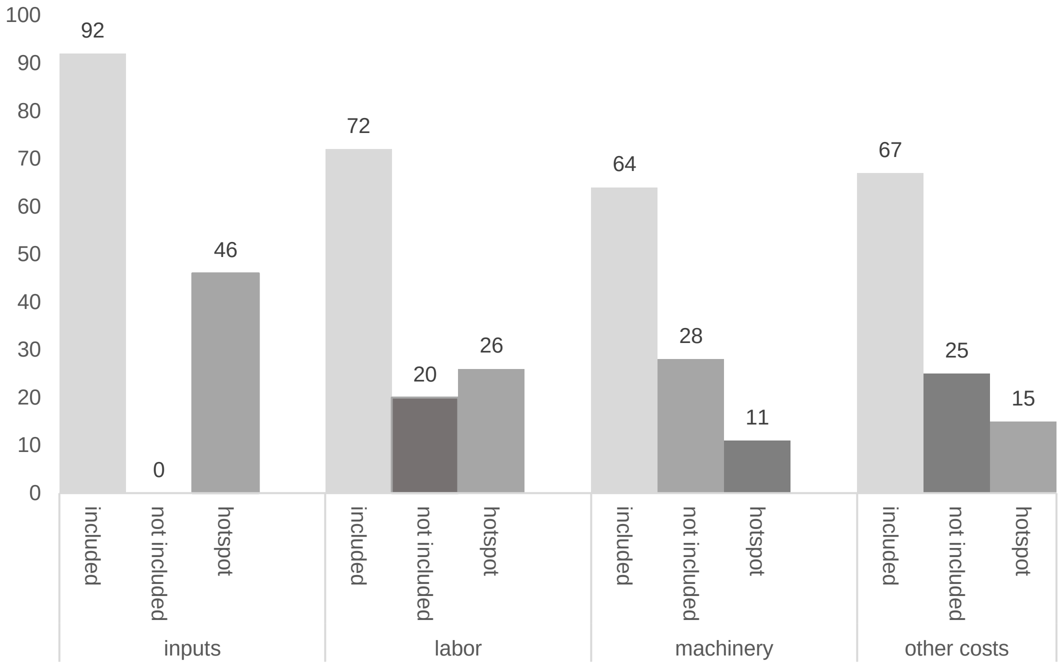

Fig. 4. Number of studies that include inputs, labor, machinery and other costs in the LCC analysis and number of studies that identified inputs, labor, machinery and other costs as an economic hotspot.

When comparing the cost hotspots for each product category, it is clear that inputs are an important cost driver for all products (Table 2). Inputs are identified as a hotspot in all studies focusing on annual crops, while for perennials, food products/ beverages and livestock production, input costs are a significant cost in 89%, 69% and 50% of the studies. For the remaining 3 studies, inputs are identified as a cost hotspot in only 1 study regarding the production of feed. Labor seems to be an important cost driver for agricultural products and food/ beverages (hotspot in 57-70% of the studies) and less important for livestock production (hotspot in 25% of studies). Machinery contributes less to the total life cycle cost of agricultural products, food/ beverages and livestock production (hotspot in 0-25% of studies). Finally, the cost type "other" was often (in 30-55% of the studies) identified as an economic hotspot among the different product categories.

Table 2. Included cost types and identified costs hotspots in the 92 LCC studies. x: cost type included, x*: cost type identified as a hotspot.

PRODUCT	**INCLUDED COSTS**				
	inputs	**labor**	**machinery**	**other**	**externalities**
Annual crop					
Baquero et al. (2011)	x	x	x	x	
Baum and Bienkowski (2020)	x*	x	x	x	
Brandão et al. (2010)	x*		x		
Canaj et al. (2021a)	x*				x*
Canaj et al. (2022)	x*		x		x*
Dorr et al. (2017)	x*				
Ekener et al. (2018)	x	x	x		
Escobar et al. (2022)	x*	x*	x*	x	
Fenollosa et al. (2014)	x*	x*	x*		
Holka (2020)	x	x	x	x	
Holka and Bieńkowski (2020)	x*	x	x*	x	
Hong et al. (2015)	x*	x*	x	x*	
Jirapornvaree et al. (2021)	x	x	x	x	
Kim et al. (2018)	x*		x	x	
Lask et al. (2020)	x*	x	x	x*	

Liaros et al. (2016)	x*	x	x	x	
Lokesh et al. (2019)	x*	x*			
Moosavi-Nezhad et al. (2022)	x	x	x		
Moungsree et al. (2022)	x*				
Pattanaik et al. (2020)	x*	x	x	x	
Saber et al. (2020)	x				x
Sanyé-Mengual et al. (2018)	x*				
Sanyé-Mengual et al. (2015)	x*	x*	x	x	
Schulte et al. (2021)	x				
Tamburini et al. (2015)	x*	x*	x	x	
Tziolas and Bournaris (2019)	x	x	x	x	
Venanzi et al. (2018)	x*	x*	x	x	
Zhen et al. (2020)	x*	x*	x	x*	
Zortea et al. (2018)	x*	x		x*	
Perennial crop					
Blanc et al. (2018)	x	x	x	x	x
Blanc et al. (2019)	x*	x*	x	x	x
Bosona et al. (2019)	x	x	x	x	
Brandão et al. (2010)	x*		x		
Canaj et al. (2021a)	x*				x*
Canaj et al. (2021b)	X*		x		
De Gennaro et al. (2012)	x	x			
De Luca et al. (2018a)	x*	x*	x*	x	
De Luca et al. (2014)	x	x		x	
Falcone et al. (2016)	x*	x*	x*	x*	
García-Herrero et al. (2022)	X*	x	x	x	
Hanif et al. (2016)	x*	x	x	x	
Iofrida et al. (2020)	x*	x*	x	x	
Lask et al. (2020)	x*	x	x	x*	
Lee et al. (2021)	x*	x	x	x*	
Lerkkasemsan and Achenie (2013)	x	x	x	x	
Lokesh et al. (2019)	x*	x*			
Luo et al. (2009)	x		x		
Mohamad et al. (2014)	x	x		x	
Nguyen et al. (2008)	x	x	x	x	
Olba-Ziety et al. (2022)	x*	x*	x*		
Omran et al. (2021)	x*	x*	x*	x	
Pari et al. (2022)	x	x		x	
Pari et al. (2020)	x	x		x	
Pergola et al. (2013)	x	x	x	x	
Rahmah et al. (2022)	x	x*	x	x	x
Roselli et al. (2020)	x	x		x	
Schulte et al. (2021)	x				
Smith and Lal (2022)	x	x	x	x	x
Soldatos (2015)	x	x	x	x	
Stillitano et al. (2016)	x*	x*	x*	x	
Strano et al. (2017)	x	x*	x	x*	
Styles et al. (2008)	x			x	

Tamburini et al. (2015)	x*	x*	x	x	
Tziolas and Bournaris (2019)	x	x	x	x	
Wagner et al. (2019a)	x	x	x	x	
Wagner et al. (2019b)	x*	x	x	x*	
Food/beverage					
Albizzati et al. (2021)	x	x	x	x	x
Amienyo and Azapagic (2016)	x*			x	
Cacace et al. (2020)	x*	x	x*	x*	
De Luca et al. (2018b)	x	x		x*	
Dobon et al. (2011)	x	x	x	x	x
Falcone et al. (2017)	x*	x*		x	
García-Herrero et al. (2021)	x	x*		x	
Garcia-Herrero et al. (2019)	x	x*	x	x*	
Gosalvitr et al. (2021)	x*		x	x	
Iotti and Bonazzi (2014)	x	x	x	x	
Konstantas et al. (2019)	x*				
Konstantas et al. (2020)	x*				
Laso et al. (2018)	x			x	
Li et al. (2021)	x*	x*			
Ribeiro et al. (2018)	x*	x*	x	x	x
Rivera and Azapagic (2016)	x*				
Ruviaro et al. (2020)	x*			x*	x
Stillitano et al. (2019)	x	x	x*	x*	
Valente et al. (2020)	x	x*	x		
Verduna et al. (2020)	x*	x*	x	x	
Wohner et al. (2020)	x			x	
Zira et al. (2021)	x	x			
Livestock					
Chen and Holden (2018)	x*	x	x	x	
Diaz et al. (2021)	x	x	x	x	
Florindo et al. (2020)	x	x*	x		
Florindo et al. (2017)	x*	x	x	x*	
Geß et al. (2022)	x	x	x	x	
Koričan et al. (2022)	x	x	x*		
Le Feon et al. (2021)	x	x	x	x	
Pexas et al. (2021)	x	x	x	x	
Feed					
Roffeis et al. (2018)	x*	x*	x		
Poultry shed					
Boggia et al. (2019)	x	x	x	x	
Beekeeping					
Strano et al. (2015)	x	x	x	x	

3.4.2. Comparison of studies

To discuss LCC results, comparable studies were grouped into 4 categories: organic vs. conventional, bio-energy vs. fossil fuel, innovative vs. conventional and valorization of byproducts vs. no valorization (Table 3). Studies which did not fit in any of the categories (42) will not be discussed. The comparison between conventional and organic production is frequently made in life cycle costing studies concerning agricultural products. There is no clear consensus between studies about which production technique scores best economically and environmentally. For example, Mohamad et al. (2014) found that the conventional scenario for olive production had the lowest life cycle cost, while the organic scenario scored best on an environmental level. Pergola et al. (2013) identified the organic production of lemon and oranges as the least costly and most environmentally sustainable scenario. In the study from Falcone et al. (2016) the conventional production scenario for vineyards was considered as the least costly and most environmentally sustainable. The production scenario with the lowest life cycle costs is not necessarily the most profitable, since there is often a higher selling price for organic products. The comparison of bio-energy from different sources with fossil fuel is also regularly made within the LCC studies. Despite the consensus about the environmental benefits of bio-energy compared to fossil fuel, there is no agreement on the least costly option (bio-energy versus fossil fuel) (e.g. contradictory results in Lerkkasemsan and Achenie (2013) and Hanif et al. (2016)). In many studies, agricultural innovations or innovations in the food industry are compared with the conventional production scenario. Innovations can be beneficial both economically and ecologically, e.g. the use of a shelf life extension technique that reduces food loss (Falcone et al., 2017). Most studies focusing on agricultural innovations or innovations in the food industry demonstrated a reduction of the environmental impact compared to the conventional scenario, whereas the life cycle cost was higher for the innovation in half of the studies. The valorization of by-products is considered beneficial from an economic and ecological point of view, within the studied articles.

Table 3. Results from LCC studies in which products or production scenarios have been compared, sorted by type of comparison.

Agricultural products: organic vs. Conventional (vs. Other)

	Lowest LCC			Best LCA		
	Organic	**Conventional**	**Other**	**Organic**	**Conventional**	**Other**
De Luca et al. (2018a)			x			x
De Luca et al. (2014)		x		x		
Falcone et al. (2016)		x			x	
Fenollosa et al. (2014)		x		x		
Iofrida et al. (2020)		x		No LCA		
Jirapornvaree et al. (2021)	x			x		
Mohamad et al. (2014)		x		x		
Pergola et al. (2013)	x			x		
Rahmah et al. (2022)		x		x		
Saber et al. (2020)	x			x		
Stillitano et al. (2016)	x			No LCA		
Strano et al. (2017)	x			x		
Zhen et al. (2020)		x				x
Zira et al. (2021)		x		x	x	Depends on indicator

Bio-energy vs. Fossil fuel

	Lowest LCC			Best LCA		
	Bio-energy	**Fossil fuel**	**Comment**	**Bio-energy**	**Fossil fuel**	**Comment**
Ekener et al. (2018)	x	x	Sugarcane lower, corn higher	x	x	Sugarcane lower, corn higher
Hanif et al. (2016)	x			x		
Koričan et al. (2022)	x			x		
Lask et al. (2020)	x		Maize	x		Wild plant mixtures
Lerkkasemsan and Achenie (2013)		x		x		
Luo et al. (2009)	x			x		
Nguyen et al. (2008)		x		x		
Wagner et al. (2019a)	x		Miscanthus	x		Miscanthus

Agricultural innovations and innovations in the food industry: innovative vs. Conventional scenario

	Lowest LCC			Best LCA		
	Innovative	**Conventional**	**Comment**	**Innovative**	**Conventional**	**Comment**
Baquero et al. (2011)		x				No LCA
Blanc et al. (2018)		x		x		
Blanc et al. (2019)		x		x		
Boggia et al. (2019)		x		x		
Canaj et al. (2021a)		x		x		
Canaj et al. (2021b)		x		x		
Canaj et al. (2022)	x			x		

Cacace et al. (2020)			Depends on product	x		
De Gennaro et al. (2012)		x			x	
De Luca et al. (2018b)	x			x		
Diaz et al. (2021)			Not clear	x		
Dobon et al. (2011)	x					No LCA
Falcone et al. (2017)	x			x		
Holka (2020)		x		x		
Holka and Bieńkowski (2020)	x	x	Reduced tillage lowest, no tillage highest	x		
Iotti and Bonazzi (2014)	x					No LCA
Lokesh et al. (2019)	x			x		
Moosavi-Nezhad et al. (2022)	x		Emission costs included	x		
Pexas et al. (2021)	x	x	Depends on strategy	x	x	Depends on indicator
Roffeis et al. (2018)		x				No LCA
Ruviaro et al. (2020)	x					No LCA
Sanyé-Mengual et al. (2015)	x			x		
Stillitano et al. (2019)		x			x	
Valente et al. (2020)	x					No LCA
Valorizing byproducts						
		Lowest LCC			**Best LCA**	
	Valorization	**No valorization**	**Comment**	**Valorization**	**No valorization**	**comment**
Gosalvitr et al. (2021)	x			x	x	Depends on method
Laso et al. (2018)	x			x		
Lokesh et al. (2019)	x			x		
Venanzi et al. (2018)	x			x		

3.4.3. Results from the integration of LCC with LCA

only 12 studies from table 3 integrated the results from LCC and LCA data. According to Zhen et al. (2020), community-supported agriculture is the most eco-efficient agricultural option compared to conventional and organic. Canaj et al. (2021a) monetized the LCA results and compared the total cost (internal + external) for different crops when using groundwater (conventional scenario) or reclaimed water (innovative scenario) for irrigation. For most crops the innovative scenario scored best overall (Canaj et al., 2021a). A similar study was done by Canaj et al. (2021b), assessing the eco-efficiency of the use of reclaimed water (innovative scenario) in vineyards. In this study the innovative scenario was also identified as the more eco-efficient one (Canaj et al., 2021b). Canaj et al. (2022) evaluated a smart irrigation system, which was identified as being less costly, with the inclusion of external costs, than farmer-led irrigation. The sustainability assessment of different olive growing systems was investigated by De Luca et al. (2018a). The AHP method was used to integrate the results of LCA, LCC and social LCA. Following this approach, the sustainability score of the low-dosage/no-tillage scenario was the highest, in comparison to the conventional and organic scenario (De Luca et al., 2018a). Ekener et al. (2018) used a multi-criteria analysis to identify fuel from sugarcane as the most sustainable option. Differences were observed depending on the perspectives of the stakeholders (Ekener et al., 2018). The sustainability of different wine-growing scenarios was analyzed by Falcone et al. (2016). The VIKOR method was implemented to show the aggregated results of different aspects of sustainability and revealed that the conventional scenario was the most sustainable (Falcone et al., 2016). Laso et al. (2018), in their assessment of the fish canning industry with a focus on anchovy species, found that the scenario where a circular economy approach was used, scored best in terms of the eco-efficiency index, compared to other waste management scenarios (landfilling and incineration). Dobon et al. (2011) used the LCA data from a previous study to integrate with the LCC data, which resulted in the finding that the use of the FBBD (flexible best-before-date)-device (innovative scenario), which can change the expiry date of a product based on temperature fluctuations, is the most sustainable if the purchasing price does not exceed the willingness-to-pay of consumers. Different manure management strategies were compared by Pexas et al. (2021). Not all innovative scenarios were more eco-efficient than the conventional one (Pexas et al., 2021). Valente et al. (2020) compared the sustainability of an innovative slaughter system with the conventional system on a radar chart. The innovative system was more sustainable for some indicators (Valente et al., 2020). Finally, Zira et al. (2021) compared the organic with the conventional pork supply chain by calculating the relative sustainability point, with the conventional chain as the benchmark. The more sustainable option was different for different sustainability indicators (Zira et al., 2021). It can be concluded that an integrated assessment can be very useful for decision-making if LCC and LCA results are contradictory, e.g. Zhen et al. (2020).

3.5. Limitations and future research

One of the most important limitations of this systematic review is that the difference between a life cycle cost analysis and other types of cost analyses is not always clear. For example, in the study of Gresta et al. (2014 the term “life cycle costing” is not explicitly mentioned, even though the methodology of the economic analysis is similar to life cycle costing. Papers that should have mentioned LCC but did not, were excluded for analysis. Currently, there is no standardized methodology for LCC, which makes it difficult to compare results between different studies. This systematic review allowed to identify different methodological inconsistencies and to recommend a certain approach for some methodological aspects. Future research should propose a standardized framework for life cycle costing studies. Thereby, a clear distinction between LCC types and different system boundaries should be made. The amount of studies that internalized externalities is still limited (12) due to methodological difficulties, indicating the need for further research. In addition, a standardized methodology for social life cycle assessment (sLCA), to assess the third pillar of sustainability, is still missing (Onat et al., 2017). Finally, the integration of the 3 pillars of sustainability through the life cycle sustainability assessment (LCSA), is also not standardized (Costa et al., 2019). Future research should tackle these methodological gaps. The LCSA framework, for instance, could be a useful tool for the analysis of the transformation of our food system. Currently, the use of this tool in the agri-food sector is very limited and most research only focuses on the environmental impacts to address increasing environmental concerns. Hence, there is a lot of potential for studies assessing the 3 pillars of sustainability.

4. Conclusions

This systematic review extracted data regarding the methodology and results of 92 life cycle costing studies within the agri-food sector. LCC has been applied for a wide range of different products and purposes, e.g. identifying cost hotspots and comparing products. An increase in LCC studies has been observed in this review, underpinning the need for an in-depth insight into the LCC methodology. At this moment, there is still no consensus amongst researchers about LCC definitions and system boundary definitions, which leads to the lack of comparability between results. In addition, data collection differs significantly between studies, for example, the inclusion or exclusion of specific cost categories. Furthermore, as each cost category has been identified as a cost hotspot in our sample, it is important that each category is considered in future LCC studies. The number of studies that included externalities for the life cycle cost analysis is still very limited. Findings further show that LCC is often applied to compare different production scenarios (e.g. conventional versus organic), innovative production methods with the traditional one, bio-energy from different sources, bio-energy with fossil fuel and the valorization of by-products compared to not valorizing side streams. While LCC can be considered a very valuable tool to assess economic sustainability, its impact can become even more far-reaching when standardized, allowing for comparability of evidence. Also the integration of LCC and other life cycle tools, often analyzed through eco-efficiency and multi-criteria decision analysis, has shown to be useful for decision-making, especially if the results from the analyses are contradictive. This review observed that there is an increased interest for a more comprehensive sustainability assessment, focusing on the 3 pillars of sustainability instead of applying only 1 life cycle tool. In conclusion, this systematic review identified inconsistencies between studies and gave recommendations for some methodological aspects. Using this systematic review as a tool, future research should further standardize the LCC framework and tackle the identified methodological issues.

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References

Albizzati PF, Tonini D, Astrup TF. A Quantitative Sustainability Assessment of Food Waste Management in the European Union. Environmental Science & Technology 2021; 55: 16099-16109. 10.1021/acs.est.1c03940

Amadei AM, De Laurentiis V, Sala S. A review of monetary valuation in life cycle assessment: State of the art and future needs. Journal of Cleaner Production 2021; 329: 129668. 10.1016/j.jclepro.2021.129668

Amienyo D, Azapagic A. Life cycle environmental impacts and costs of beer production and consumption in the UK. International Journal of Life Cycle Assessment 2016; 21: 492-509. 10.1007/s11367-016-1028-6

Arendt R, Bachmann TM, Motoshita M, Bach V, Finkbeiner M. Comparison of Different Monetization Methods in LCA: A Review. Sustainability 2020; 12. 10.3390/su122410493

Baldini C, Gardoni D, Guarino M. A critical review of the recent evolution of Life Cycle Assessment applied to milk production. Journal of Cleaner Production 2017; 140: 421-435. 10.1016/j.jclepro.2016.06.078

Baquero G, Esteban B, Riba JR, Rius A, Puig R. An evaluation of the life cycle cost of rapeseed oil as a straight vegetable oil fuel to replace petroleum diesel in agriculture. Biomass & Bioenergy 2011; 35: 3687-3697. 10.1016/j.biombioe.2011.05.028

Baum R, Bienkowski J. Eco-Efficiency in Measuring the Sustainable Production of Agricultural Crops. Sustainability 2020; 12. 10.3390/su12041418

Blanc S, Accastello C, Girgenti V, Brun F, Mosso A. Innovative Strategies for the Raspberry Supply Chain: An Environmental and Economic Assessment. Quality-Access to Success 2018; 19: 139-142.

Blanc S, Massaglia S, Brun F, Peano C, Mosso A, Giuggioli NR. Use of Bio-Based Plastics in the Fruit Supply Chain: An Integrated Approach to Assess Environmental, Economic, and Social Sustainability. Sustainability 2019; 11: 2475. 10.3390/su11092475

Boggia A, Paolotti L, Antegiovanni P, Fagioli FF, Rocchi L. Managing ammonia emissions using no-litter flooring system for broilers: Environmental and economic analysis. Environmental Science & Policy 2019; 101: 331-340. 10.1016/j.envsci.2019.09.005

Bosona T, Gebresenbet G, Dyjakon A. Implementing life cycle cost analysis methodology for evaluating agricultural pruning-to-energy initiatives. Bioresource Technology Reports 2019; 6: 54-62. 10.1016/j.biteb.2019.02.006

Brandão M, Clift R, Milà LC, Basson L. A life-cycle approach to characterising environmental and economic impacts of multifunctional land-use systems: An integrated assessment in the UK. Sustainability 2010; 2: 3747-3776. 10.3390/su2123747

Cacace F, Bottani E, Rizzi A, Vignali G. Evaluation of the economic and environmental sustainability of high pressure processing of foods. Innovative Food Science & Emerging Technologies 2020; 60. 10.1016/j.ifset.2019.102281

Canaj K, Mehmeti A, Berbel J. The Economics of Fruit and Vegetable Production Irrigated with Reclaimed Water Incorporating the Hidden Costs of Life Cycle Environmental Impacts. Resources-Basel 2021a; 10. 10.3390/resources10090090

Canaj K, Morrone D, Roma R, Boari F, Cantore V, Todorovic M. Reclaimed Water for Vineyard Irrigation in a Mediterranean Context: Life Cycle Environmental Impacts, Life Cycle Costs, and Eco-Efficiency. Water 2021b; 13. 10.3390/w13162242

Canaj K, Parente A, D'imperio M, Boari F, Buono V, Toriello M, et al. Can precise irrigation support the sustainability of protected cultivation? A life-cycle assessment and life-cycle cost analysis. Water (Switzerland) 2022; 14. 10.3390/w14010006

Chen W, Holden NM. Tiered life cycle sustainability assessment applied to a grazing dairy farm. Journal of Cleaner Production 2018; 172: 1169-1179. 10.1016/j.jclepro.2017.10.264

Costa D, Quinteiro P, Dias AC. A systematic review of life cycle sustainability assessment: Current state, methodological challenges, and implementation issues. Science of The Total Environment 2019; 686: 774-787. 10.1016/j.scitotenv.2019.05.435

Darton RC. Chapter 14 - Setting a policy for sustainability: The importance of measurement. In: Klemeš JJ, editor. Assessing and Measuring Environmental Impact and Sustainability. Butterworth-Heinemann, Oxford, 2015, pp. 479-496. 10.1016/B978-0-12-799968-5.00014-2

De Gennaro B, Notarnicola B, Roselli L, Tassielli G. Innovative olive-growing models: an environmental and economic assessment. Journal of Cleaner Production 2012; 28: 70-80. 10.1016/j.jclepro.2011.11.004

De Luca AI, Falcone G, Stillitano T, Iofrida N, Strano A, Gulisano G. Evaluation of sustainable innovations in olive growing systems: A Life Cycle Sustainability Assessment case study in southern Italy. Journal of Cleaner Production 2018a; 171: 1187-1202. 10.1016/j.jclepro.2017.10.119

De Luca AI, Falcone G, Stillitano T, Strano A, Gulisano G. Sustainability assessment of quality-oriented citrus growing systems in Mediterranean area. Quality - Access to Success 2014; 15: 103-108.

De Luca AI, Iofrida N, Leskinen P, Stillitano T, Falcone G, Strano A, et al. Life cycle tools combined with multi-criteria and participatory methods for agricultural sustainability: Insights from a systematic and critical review. Science of The Total Environment 2017; 595: 352-370. 10.1016/j.scitotenv.2017.03.284

De Luca AI, Stillitano T, Falcone G, Squeo G, Caponio F, Strano A, et al. Economic and environmental assessment of extra virgin olive oil processing innovations. Chemical Engineering Transactions 2018b; 67: 133-138. 10.3303/CET1867023

De Menna F, Dietershagen J, Loubiere M, Vittuari M. Life cycle costing of food waste: A review of methodological approaches. Waste Management 2018; 73: 1-13. 10.1016/j.wasman.2017.12.032

Diaz F, Vignati JA, Marchi B, Paoli R, Zanoni S, Romagnoli F. Effects of Energy Efficiency Measures in the Beef Cold Chain: A Life Cycle-based Study. Environmental and Climate Technologies 2021; 25: 343-355. 10.2478/rtuect-2021-0025

Djekic I, Batlle-Bayer L, Bala A, Fullana-i-Palmer P, Jambrak AR. Role of the Food Supply Chain Stakeholders in Achieving UN SDGs. Sustainability 2021; 13: 9095. 10.3390/su13169095

Dobon A, Cordero P, Kreft F, Ostergaard SR, Antvorskov H, Robertsson M, et al. The sustainability of communicative packaging concepts in the food supply chain. A case study: part 2. Life cycle costing and sustainability assessment. International Journal of Life Cycle Assessment 2011; 16: 537-547. 10.1007/s11367-011-0291-9

Dorr E, Sanye-Mengual E, Gabrielle B, Grard BJP, Aubry C. Proper selection of substrates and crops enhances the sustainability of Paris rooftop garden. Agronomy for Sustainable Development 2017; 37. 10.1007/s13593-017-0459-1

Ekener E, Hansson J, Larsson A, Peck P. Developing Life Cycle Sustainability Assessment methodology by applying values-based sustainability weighting - Tested on biomass based and fossil transportation fuels. Journal of Cleaner Production 2018; 181: 337-351. 10.1016/j.jclepro.2018.01.211

Escobar N, Bautista I, Pena N, Fenollosa ML, Osca JM, Sanjuan N. Life Cycle Thinking for the environmental and financial assessment of rice management systems in the Senegal River Valley. Journal of Environmental Management 2022; 310. 10.1016/j.jenvman.2022.114722

Falcone G, De Luca AI, Stillitano T, Iofrida N, Strano A, Piscopo A, et al. Shelf life extension to reduce food losses: The case of Mozzarella Cheese. Chemical Engineering Transactions 2017; 57: 1849-1854. 10.3303/CET1757309

Falcone G, De Luca AI, Stillitano T, Strano A, Romeo G, Gulisano G. Assessment of Environmental and Economic Impacts of Vine-Growing Combining Life Cycle Assessment, Life Cycle Costing and Multicriterial Analysis. Sustainability 2016; 8: 793. 10.3390/su8080793

FAO. Building a Common Vision for Sustainable Food and Agriculture. Principles and Approaches, Rome, 2014.

Fenollosa ML, Ribal J, Lidon A, Bautista I, Juraske R, Clemente G, et al. Influence of Management Practices on Economic and Environmental Performance of Crops. A Case Study in Spanish Horticulture. Agroecology and Sustainable Food Systems 2014; 38: 635-659. 10.1080/21683565.2014.896302

Florindo TJ, Florindo G, Ruviaro CF, Pinto AT. Multicriteria decision-making and probabilistic weighing applied to sustainable assessment of beef life cycle. Journal of Cleaner Production 2020; 242. 10.1016/j.jclepro.2019.118362

Florindo TJ, Florindo G, Talamini E, da Costa JS, Ruviaro CF. Carbon footprint and Life Cycle Costing of beef cattle in the Brazilian midwest. Journal of Cleaner Production 2017; 147: 119-129. 10.1016/j.jclepro.2017.01.021

García-Herrero L, Brenes-Peralta L, Leschi F, Vittuari M. Integrating Life Cycle Thinking in a policy decision tool: Its application in the pineapple production in Dominican Republic. Journal of Cleaner Production 2022; 360. 10.1016/j.jclepro.2022.132094

García-Herrero L, Costello C, De Menna F, Schreiber L, Vittuari M. Eating away at sustainability. Food consumption and waste patterns in a US school canteen. Journal of Cleaner Production 2021; 279. 10.1016/j.jclepro.2020.123571

Garcia-Herrero L, De Menna F, Vittuari M. Food waste at school. The environmental and cost impact of a canteen meal. Waste Management 2019; 100: 249-258. 10.1016/j.wasman.2019.09.027

Gava O, Bartolini F, Venturi F, Brunori G, Zinnai A, Pardossi A. A Reflection of the Use of the Life Cycle Assessment Tool for Agri-Food Sustainability. Sustainability 2019; 11: 71. 10.3390/su11010071

Geß A, Tolsdorf A, Ko N. A life cycle perspective of lamb meat production systems from Turkey and the EU. Small Ruminant Research 2022; 208. 10.1016/j.smallrumres.2022.106637

Gladek E, Fraser M, Roemers G, Sabag Muñoz O, Kennedy E, Hirsch P. The global food system: an analysis. Metabolic, Amsterdam 2016.

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. Food Security: The Challenge of Feeding 9 Billion People. Science 2010; 327: 812-818. 10.1126/science.1185383

Gomersall JS, Jadotte YT, Xue Y, Lockwood S, Riddle D, Preda A. Conducting systematic reviews of economic evaluations. JBI Evidence Implementation 2015; 13: 170-178. 10.1097/xeb.0000000000000063

Gosalvitr P, Cuellar-Franca RM, Smith R, Azapagic A. Integrating process modelling and sustainability assessment to improve the environmental and economic sustainability in the cheese industry. Sustainable Production and Consumption 2021a; 28: 969-986. 10.1016/j.spc.2021.07.022

Gresta F, De Luca AI, Strano A, Falcone G, Santonoceto C, Anastasi U, et al. Economic and environmental sustainability analysis of guar (Cyamopsis tetragonoioba L.) farming process in a Mediterranean area: two case studies. Italian Journal of Agronomy 2014; 9: 20-24. 10.4081/ija.2014.565

Guinée JB, Heijungs R, Huppes G, Zamagni A, Masoni P, Buonamici R, et al. Life Cycle Assessment: Past, Present, and Future. Environmental Science & Technology 2011; 45: 90-96. 10.1021/es101316v

Hanif M, Mahlia TMI, Aditiya HB, Chong WT, Nasruddin. Techno-economic and environmental assessment of bioethanol production from high starch and root yield Sri Kanji 1 cassava in Malaysia. Energy Reports 2016; 2: 246-253. 10.1016/j.egyr.2016.03.004

Holka M. Assessment of carbon footprint and life cycle costs of winter wheat (Triticum Aestivum L.) production in different soil tillage systems. Applied Ecology and Environmental Research 2020; 18: 5841-5855. 10.15666/aeer/1804_58415855

Holka M, Bieńkowski J. Carbon footprint and life-cycle costs of maize production in conventional and non-inversion tillage systems. Agronomy 2020; 10. 10.3390/agronomy10121877

Hong JM, Zhou J, Hong JL. Environmental and economic impact of furfuralcohol production using corncob as a raw material. International Journal of Life Cycle Assessment 2015; 20: 623-631. 10.1007/s11367-015-0854-2

Hoogmartens R, Van Passel S, Van Acker K, Dubois M. Bridging the gap between LCA, LCC and CBA as sustainability assessment tools. Environmental Impact Assessment Review 2014; 48: 27-33. 10.1016/j.eiar.2014.05.001

Hunkeler D, Lichtenvort K, Rebitzer G. Environmental Life Cycle Costing: CRC Press, 2008.

Iofrida N, Stillitano T, Falcone G, Gulisano G, Nicolo BF, De Luca AI. The socio-economic impacts of organic and conventional olive growing in Italy. New Medit 2020; 19: 117-131. 10.30682/nm2001h

Iotti M, Bonazzi G. The application of Life Cycle Cost (LCC) approach to quality food production: A comparative analysis in the parma pdo ham sector. American Journal of Applied Sciences 2014; 11: 1492-1506. 10.3844/ajassp.2014.1492.1506

ISO. ISO 14040: Environmental management—Life cycle assessment—Principles and framework. Environmental Management 2006a; 3: 28.

ISO. ISO 14044: 2006-environmental management-life cycle assessment-requirements and guidelines. Genf, 2006b.

ISO. ISO 15686–5: Buildings and constructed assets-service-life planning-Part 5: Life-cycle costing, 2008.

ISO. ISO 15663 Petroleum, petrochemical and natural gas industries—Life cycle costing. International Organization for Standardization (ISO) Geneva, Switzerland, 2021.

Jirapornvaree I, Suppadit T, Kumar V. Assessing the economic and environmental impact of jasmine rice production: Life cycle assessment and Life Cycle Costs analysis. Journal of Cleaner Production 2021; 303. 10.1016/j.jclepro.2021.127079

Kim E, Jung J, Hapsari G, Kang S, Kim K, Yoon S, et al. Economic and environmental sustainability and public perceptions of rooftop farm versus extensive garden. Building and Environment 2018; 146: 206-215. 10.1016/j.buildenv.2018.09.046

Kloepffer W. Life cycle sustainability assessment of products. The International Journal of Life Cycle Assessment 2008; 13: 89. 10.1065/lca2008.02.376

Konstantas A, Stamford L, Azapagic A. Economic sustainability of food supply chains: Life cycle costs and value added in the confectionary and frozen desserts sectors. Science of the Total Environment 2019; 670: 902-914. 10.1016/j.scitotenv.2019.03.274

Konstantas A, Stamford L, Azapagic A. A framework for evaluating life cycle eco-efficiency and an application in the confectionary and frozen-desserts sectors. Sustainable Production and Consumption 2020; 21: 192-203. 10.1016/j.spc.2019.12.006

Koričan M, Perčić M, Vladimir N, Soldo V, Jovanović I. Environmental and economic assessment of mariculture systems using a high share of renewable energy sources. Journal of Cleaner Production 2022; 333. 10.1016/j.jclepro.2021.130072

Lask J, Martínez Guajardo A, Weik J, von Cossel M, Lewandowski I, Wagner M. Comparative environmental and economic life cycle assessment of biogas production from perennial wild plant mixtures and maize (Zea mays L.) in southwest Germany. GCB Bioenergy 2020. 10.1111/gcbb.12715

Laso J, Garcia-Herrero I, Margallo M, Vazquez-Rowe I, Fullana P, Bala A, et al. Finding an economic and environmental balance in value chains based on circular economy thinking: An eco-efficiency methodology applied to the fish canning industry. Resources Conservation and Recycling 2018; 133: 428-437. 10.1016/j.resconrec.2018.02.004

Le Feon S, Dubois T, Jaeger C, Wilfart A, Akkal-Corfini N, Bacenetti J, et al. DEXiAqua, a Model to Assess the Sustainability of Aquaculture Systems: Methodological Development and Application to a French Salmon Farm. Sustainability 2021; 13. 10.3390/su13147779

Lee ZY, Liew PY, Woon KS, Tan LS, Tamunaidu P, Klemeš JJ. Life-Cycle Environmental and Cost Analysis of Palm Biomass-based Bio-Ethanol Production in Malaysia. Chemical Engineering Transactions 2021; 89: 85-90. 10.3303/CET2189015

Lerkkasemsan N, Achenie LEK. Life cycle costs and life cycle assessment for the harvesting, conversion, and the use of switchgrass to produce electricity. International Journal of Chemical Engineering 2013. 10.1155/2013/492058

Li J, Li W, Wang L, Jin B. Environmental and cost impacts of food waste in university canteen from a life cycle perspective. Energies 2021; 14. 10.3390/en14185907

Liaros S, Botsis K, Xydis G. Technoeconomic evaluation of urban plant factories: The case of basil (Ocimum basilicum). Science of the Total Environment 2016; 554: 218-227. 10.1016/j.scitotenv.2016.02.174

Lokesh K, West C, Kuylenstierna JC, Fan JJ, Budarin V, Priecel P, et al. Economic and agronomic impact assessment of wheat straw based alkyl polyglucoside produced using green chemical approaches. Journal of Cleaner Production 2019; 209: 283-296. 10.1016/j.jclepro.2018.10.220

Luo L, van der Voet E, Huppes G. Life cycle assessment and life cycle costing of bioethanol from sugarcane in Brazil. Renewable & Sustainable Energy Reviews 2009; 13: 1613-1619. 10.1016/j.rser.2008.09.024

Meier MS, Stoessel F, Jungbluth N, Juraske R, Schader C, Stolze M. Environmental impacts of organic and conventional agricultural products – Are the differences captured by life cycle assessment? Journal of Environmental Management 2015; 149: 193-208. 10.1016/j.jenvman.2014.10.006

Mohamad RS, Verrastro V, Cardone G, Bteich MR, Favia M, Moretti M, et al. Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment and Life Cycle Costing perspectives. Journal of Cleaner Production 2014; 70: 78-89. 10.1016/j.jclepro.2014.02.033

Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 2009; 339: b2535. 10.1136/bmj.b2535

Moosavi-Nezhad M, Salehi R, Aliniaeifard S, Winans KS, Nabavi-Pelesaraei A. An analysis of energy use and economic and environmental impacts in conventional tunnel and LED-equipped vertical systems in healing and acclimatization of grafted watermelon seedlings. Journal of Cleaner Production 2022; 361. 10.1016/j.jclepro.2022.132069

Moungsree S, Neamhom T, Polprasert S, Patthanaissaranukool W. Carbon footprint and life cycle costing of maize production in Thailand with temporal and geographical resolutions. International Journal of Life Cycle Assessment 2022. 10.1007/s11367-022-02021-4

Neugebauer S, Forin S, Finkbeiner M. From Life Cycle Costing to Economic Life Cycle Assessment—Introducing an Economic Impact Pathway. Sustainability 2016; 8: 428. 10.3390/su8050428

Nguyen TLT, Gheewala SH, Bonnet S. Life cycle cost analysis of fuel ethanol produced from cassava in Thailand. International Journal of Life Cycle Assessment 2008; 13: 564-573. 10.1007/s11367-008-0035-7

Norris GA. Integrating life cycle cost analysis and LCA. The International Journal of Life Cycle Assessment 2001; 6: 118-120. 10.1007/BF02977849

Notarnicola B, Sala S, Anton A, McLaren SJ, Saouter E, Sonesson U. The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. Journal of Cleaner Production 2017; 140: 399-409. 10.1016/j.jclepro.2016.06.071

Olba-Ziety E, Stolarski MJ, Krzyzaniak M, Roj E, Tyskiewicz K, Luczynski MK. Supercritical production of extract from poplar containing bioactive substances - An economic analysis. Industrial Crops and Products 2022; 184. 10.1016/j.indcrop.2022.115094

Omolayo Y, Feingold BJ, Neff RA, Romeiko XX. Life cycle assessment of food loss and waste in the food supply chain. Resources, Conservation and Recycling 2021; 164: 105119. 10.1016/j.resconrec.2020.105119

Omran N, Sharaai AH, Hashim AH. Visualization of the Sustainability Level of Crude Palm Oil Production: A Life Cycle Approach. Sustainability 2021; 13. 10.3390/su13041607

Onat NC, Kucukvar M, Halog A, Cloutier S. Systems Thinking for Life Cycle Sustainability Assessment: A Review of Recent Developments, Applications, and Future Perspectives. Sustainability 2017; 9: 706. 10.3390/su9050706

Pari L, Alexopoulou E, Stefanoni W, Latterini F, Cavalaris C, Palmieri N. The Eco-Efficiency of Castor Supply Chain: A Greek Case Study. Agriculture-Basel 2022; 12. 10.3390/agriculture12020206

Pari L, Suardi A, Stefanoni W, Latterini F, Palmieri N. Environmental and Economic Assessment of Castor Oil Supply Chain: A Case Study. Sustainability 2020; 12. 10.3390/su12166339

Pattanaik L, Padhi SK, Hariprasad P, Naik SN. Life cycle cost analysis of natural indigo dye production from Indigofera tinctoria L. plant biomass: a case study of India. Clean Technologies and Environmental Policy 2020; 22: 1639-1654. 10.1007/s10098-020-01914-y

Peña A, Rovira-Val MR. A longitudinal literature review of life cycle costing applied to urban agriculture. International Journal of Life Cycle Assessment 2020. 10.1007/s11367-020-01768-y

Pergola M, D'Amico M, Celano G, Palese AM, Scuderi A, Di Vita G, et al. Sustainability evaluation of Sicily's lemon and orange production: An energy, economic and environmental analysis. Journal of Environmental Management 2013; 128: 674-682. 10.1016/j.jenvman.2013.06.007

Pexas G, Mackenzie SG, Wallace M, Kyriazakis I. Accounting for spatial variability in life cycle cost-effectiveness assessments of environmental impact abatement measures. International Journal of Life Cycle Assessment 2021; 26: 1236-1253. 10.1007/s11367-021-01915-z

Pizzol M, Weidema B, Brandão M, Osset P. Monetary valuation in Life Cycle Assessment: a review. Journal of Cleaner Production 2015; 86: 170-179. 10.1016/j.jclepro.2014.08.007

Rahmah DM, Putra AS, Ishizaki R, Noguchi R, Ahamed T. A Life Cycle Assessment of Organic and Chemical Fertilizers for Coffee Production to Evaluate Sustainability toward the Energy-Environment-Economic Nexus in Indonesia. Sustainability 2022; 14. 10.3390/su14073912

Ribeiro I, Sobral P, Pecas P, Henriques E. A sustainable business model to fight food waste. Journal of Cleaner Production 2018; 177: 262-275. 10.1016/j.jclepro.2017.12.200

Rivera XCS, Azapagic A. Life cycle costs and environmental impacts of production and consumption of ready and home-made meals. Journal of Cleaner Production 2016; 112: 214-228. 10.1016/j.jclepro.2015.07.111

Roffeis M, Wakefield ME, Almeida J, Valada TRA, Devic E, Kone N, et al. Life cycle cost assessment of insect based feed production in West Africa. Journal of Cleaner Production 2018; 199: 792-806. 10.1016/j.jclepro.2018.07.179

Roos A, Ahlgren S. Consequential life cycle assessment of bioenergy systems – A literature review. Journal of Cleaner Production 2018; 189: 358-373. 10.1016/j.jclepro.2018.03.233

Roselli L, Casieri A, de Gennaro BC, Sardaro R, Russo G. Environmental and Economic Sustainability of Table Grape Production in Italy. Sustainability 2020; 12. 10.3390/su12093670

Ruviaro CF, de Leis CM, Florindo TJ, de Medeiros Florindo GIB, da Costa JS, Tang WZ, et al. Life cycle cost analysis of dairy production systems in Southern Brazil. Science of the Total Environment 2020; 741. 10.1016/j.scitotenv.2020.140273

Saber Z, Esmaeili M, Pirdashti H, Motevali A, Nabavi-Pelesaraei A. Exergoenvironmental-Life cycle cost analysis for conventional, low external input and organic systems of rice paddy production. Journal of Cleaner Production 2020; 263. 10.1016/j.jclepro.2020.121529

Sala S, Farioli F, Zamagni A. Life cycle sustainability assessment in the context of sustainability science progress (part 2). The International Journal of Life Cycle Assessment 2013a; 18: 1686-1697. 10.1007/s11367-012-0509-5

Sala S, Farioli F, Zamagni A. Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment: Part 1. The International Journal of Life Cycle Assessment 2013b; 18: 1653-1672. 10.1007/s11367-012-0508-6

Sanyé-Mengual E, Gasperi D, Michelon N, Orsini F, Ponchia G, Gianquinto G. Eco-efficiency assessment and food security potential of home gardening: A case study in Padua, Italy. Sustainability (Switzerland) 2018; 10. 10.3390/su10072124

Sanyé-Mengual E, Oliver-Solà J, Montero JI, Rieradevall J. An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level. International Journal of Life Cycle Assessment 2015; 20: 350-366. 10.1007/s11367-014-0836-9

Schau EM, Fet AM. LCA studies of food products as background for environmental product declarations. The International Journal of Life Cycle Assessment 2008; 13: 255-264. 10.1065/lca2007.12.372

Schulte M, Lewandowski I, Pude R, Wagner M. Comparative life cycle assessment of bio-based insulation materials: Environmental and economic performances. Global Change Biology Bioenergy 2021; 13: 979-998. 10.1111/gcbb.12825

Silva VL, Sanjuán N. Opening up the black box: A systematic literature review of life cycle assessment in alternative food processing technologies. Journal of Food Engineering 2019; 250: 33-45. 10.1016/j.jfoodeng.2019.01.010

Smith M, Lal P. Environmental and economic assessment of hard apple cider using an integrated LCA-LCC approach. Sustainable Production and Consumption 2022; 32: 282-295. 10.1016/j.spc.2022.04.026

Soldatos P. Economic Aspects of Bioenergy Production from Perennial Grasses in Marginal Lands of South Europe. Bioenergy Research 2015; 8: 1562-1573. 10.1007/s12155-015-9678-y

Stillitano T, De Luca AI, Falcone G, Spada E, Gulisano G, Strano A. Economic profitability assessment of mediterranean olive growing systems. Bulgarian Journal of Agricultural Science 2016; 22: 517-526.

Stillitano T, Falcone G, De Luca AI, Piga A, Conte P, Strano A, et al. Innovative technologies in EVO oil extraction: an economic and environmental impact analysis. Rivista Italiana Delle Sostanze Grasse 2019; 96: 223-230.

Strano A, Falcone G, Nicolo BF, Stillitano T, De Luca AI, Nesci FS, et al. 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 2017; 41: 1124-1145. 10.1080/21683565.2017.1357064

Strano A, Stillitano T, De Luca AI, Falcone G, Gulisano G. Profitability analysis of small-scale beekeeping firms by using life cycle costing (LCC) methodology. American Journal of Agricultural and Biological Science 2015; 10: 116-127. 10.3844/ajabssp.2015.116.127

Styles D, Thorne F, Jones MB. Energy crops in Ireland: An economic comparison of willow and Miscanthus production with conventional farming systems. Biomass & Bioenergy 2008; 32: 407-421. 10.1016/j.biombioe.2007.10.012

Sutherland CS, Yukich J, Goeree R, Tediosi F. A literature review of economic evaluations for a neglected tropical disease: human African trypanosomiasis ("sleeping sickness"). PLoS neglected tropical diseases 2015; 9: e0003397-e0003397. 10.1371/journal.pntd.0003397

Swarr TE, Hunkeler D, Klöpffer W, Pesonen H-L, Ciroth A, Brent AC, et al. Environmental life-cycle costing: a code of practice. The International Journal of Life Cycle Assessment 2011; 16: 389-391. 10.1007/s11367-011-0287-5

Tamburini E, Pedrini P, Marchetti MG, Fano EA, Castaldelli G. Life Cycle Based Evaluation of Environmental and Economic Impacts of Agricultural Productions in the Mediterranean Area. Sustainability 2015; 7: 2915-2935. 10.3390/su7032915

Tziolas E, Bournaris T. Economic and Environmental Assessment of Agro-Energy Districts in Northern Greece: a Life Cycle Assessment Approach. Bioenergy Research 2019; 12: 1145-1162. 10.1007/s12155-019-10020-x

Valente C, Moller H, Johnsen FM, Saxegard S, Brunsdon ER, Alvseike OA. Life cycle sustainability assessment of a novel slaughter concept. Journal of Cleaner Production 2020; 272. 10.1016/j.jclepro.2020.122651

Venanzi S, Pezzolla D, Cecchini L, Pauselli M, Ricci A, Sordi A, et al. Use of agricultural by-products in the development of an agro-energy chain: A case study from the Umbria region. Science of the Total Environment 2018; 627: 494-505. 10.1016/j.scitotenv.2018.01.176

Verduna T, Blanc S, Merlino VM, Cornale P, Battaglini LM. Sustainability of Four Dairy Farming Scenarios in an Alpine Environment: The Case Study of Toma di Lanzo Cheese. Frontiers in Veterinary Science 2020; 7. 10.3389/fvets.2020.569167

Wagner M, Kamp L, Graeff-Honninger S, Lewandowski I. Environmental and Economic Performance of Yacon (Smallanthus sonchifolius) Cultivated for Fructooligosaccharide Production. Sustainability 2019a; 11. 10.3390/su11174581

Wagner M, Mangold A, Lask J, Petig E, Kiesel A, Lewandowski I. Economic and environmental performance of miscanthus cultivated on marginal land for biogas production. Global Change Biology Bioenergy 2019b; 11: 34-49. 10.1111/gcbb.12567

Wohner B, Gabriel VH, Krenn B, Krauter V, Tacker M. Environmental and economic assessment of food-packaging systems with a focus on food waste. Case study on tomato ketchup. Science of the Total Environment 2020; 738. 10.1016/j.scitotenv.2020.139846

World Business Council for Sustainable Development. Eco-efficiency: Learning Module. Conches-Geneva Switzerland, 2006.

Yang N, Li F, Liu Y, Dai T, Wang Q, Zhang J, et al. Environmental and Economic Life-Cycle Assessments of Household Food Waste Management Systems: A Comparative Review of Methodology and Research Progress. Sustainability 2022; 14: 7533. 10.3390/su14137533

Zhen H, Gao W, Jia L, Qiao Y, Ju X. Environmental and economic life cycle assessment of alternative greenhouse vegetable production farms in peri-urban Beijing, China. Journal of Cleaner Production 2020; 269. 10.1016/j.jclepro.2020.122380

Zira S, Rydhmer L, Ivarsson E, Hoffmann R, Roos E. A life cycle sustainability assessment of organic and conventional pork supply chains in Sweden. Sustainable Production and Consumption 2021; 28: 21-38. 10.1016/j.spc.2021.03.028

Zortea RB, Maciel VG, Passuello A. Sustainability assessment of soybean production in Southern Brazil: A life cycle approach. Sustainable Production and Consumption 2018; 13: 102-112. 10.1016/j.spc.2017.11.002