A customized multi-cycle model for measuring the sustainability of circular pathways in agri-food supply chains

Original
A customized multi-cycle model for measuring the sustainability of circular pathways in agri-food supply chains / Stillitano, T., Falcone, G., Iofrida, N., Spada, E., Gulisano, G., De Luca, A.I.. - In: SCIENCE OF THE TOTAL ENVIRONMENT. - ISSN 1879-1026. - 844:157229(2022), pp. 1-11. [10.1016/j.scitotenv.2022.157229]

Published
DOI: http://doi.org/10.1016/j.scitotenv.2022.157229

Science of the Total Environment xxx (xxxx) 157229

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com

A customized multi-cycle model for measuring the sustainability of circular pathways in agri-food supply chains

Teodora Stillitano, Giacomo Falcone*, Nathalie Iofrida, Emanuele Spada, Giovanni Gulisano, Anna Irene De Luca

Department of Agriculture (AGRARIA), University Mediterranea of Reggio Calabria, 89122 Reggio Calabria, Italy

ARTICLE INFO

Editor: Jacopo Bacenetti

Keywords:
Sustainability
Life cycle methodologies
Multi-cycle model
Circular economy
Agri-food sector
Olive-oil supply chain

ABSTRACT

Circular economy (CE) is claimed to be a promising pathway to achieve the Sustainable Development Goals (SDGs), but a reliable metric is needed to validate closed-loop strategies by measuring sustainability performances together with the degree of circularity. A significant contribution is offered by Life Cycle (LC) scholars in terms of methodological advances and operational tools for different sectors, also those more complex such as the agro-industrial systems that encompass biological and anthropogenic variables at different scales. However, to date, LC methodologies have not yet answered how to model the complexity of circular pathways. LC evaluations are often modelled for cradle-to-grave analyses, while a circularity evaluation would require an extension of the system boundaries to more interconnected life cycles, orienting towards a cradle-to-cradle perspective. This research gap led us to propose a multi-cycle approach with expanded assessment boundaries, including co-products, into a cradle-to-cradle perspective, in an attempt to internalize circularity impacts. The customized LC framework here proposed is based on the Life Cycle Assessment (LCA), the Environmental Life Cycle Costing (ELCC) in terms of internal and external costs, and the Social Life Cycle Assessment (SLCA) in terms of Psychosocial Risk Factor (PRF) impact pathway. The model is designed to be applied to the olive-oil sector, which commonly causes significant impacts by generating many by-products whose management is often problematic. Results are expected to show that the customized LC framework proposed can better highlight the environmental and socioeconomic performances of the system of cycles, allowing CE to deliver its promises of sustainability, as the circularity of materials per se is a means, not an end in itself.

1. Introduction

In line with the 2030 Sustainable Development Goals (SDGs), the global reference framework for sustainable development signed in 2015 by the United Nations, the European Commission prepared, at a macro level, the "Action Plan for Circular Economy" for a cleaner and more competitive Europe, trying to achieve a transition towards the climate neutrality by 2050 and decoupling economic growth from resource use (European Commission, 2020). Rodriguez-Anton et al. (2019), by analysing the relationship between the CE and SDGs, asserted that an increase in the recycling rate of municipal waste, the recycling of biological waste, the use rate of circular material could significantly improve the sustainability of EU countries.

At a micro level, circularity practices can represent a practical chance to integrate sustainability into corporate goals (Maranesi and De Giovanni, 2020). According to Machin Ferrero et al. (2022), to increase the sustainability of products, Circular Economy (CE) strategies implementation must seek to return to the process as many materials and energy flows as possible by reducing waste and pollution. To measure product circularity performance several methods and tools have been tested (Ellen MacArthur Foundation, 2015; Saidani et al., 2017). However, most circularity metrics focus their analysis on material flows occurring in relation to a process or a product, overlooking the nature of the materials in circulation and especially in not considering the environmental, economic, and social impacts generated by circular strategies. As stressed by Goddin et al. (2019), who update the original methodology for calculating the Material Circularity Indicator (MCI) (Ellen MacArthur Foundation, 2015), to overcome these limitations, a circularity assessment should find its methodological complement in Life Cycle (LC) management tools. Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (SLCA) have long

---

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

https://doi.org/10.1016/j.scitotenv.2022.157229
Received 9 May 2022; Received in revised form 4 July 2022; Accepted 4 July 2022
0048-9697/© 20XX

been recognised by the scientific community as tools that enable comprehensive sustainability assessments (De Luca et al., 2017).

In recent years, LC scholars and practitioners are also making a significant contribution in terms of methodological advances and operational tools to circular economy studies (Niero and Hauschild, 2017; Rigamonti and Mancini, 2021). However, despite these efforts, LC methodologies still have not consensually solved how to model the complexity of closed-loop strategies (Corona et al., 2019). In other words, to fully exploit the potential of LC methodologies, which originally have been conceived mainly for linear processes, should be properly customized for circular systems. Indeed, LC evaluations are often modelled for cradle-to-grave analyses, while a circularity evaluation would require an extension of the system boundaries to more interconnected life cycles, always orienting towards a cradle-to-cradle perspective, to include the reuse of materials, their remanufacture and recycling. Therefore, to combine the two approaches, it is necessary to extend the boundaries of the traditional LC methodologies and assess the likely impacts for each next life cycle, in a continuous or closed process of production, recycling and reuse. However, the difficulty lies in defining at which level, to what extent and from which perspective these loops should be closed. As argued by Liu and Ramakrishna (2021), when comparing circularity indicators with LC approaches, it must be ensured that the metrics are indeed being calculated on an appropriate basis.

Besides addressing the system boundary issue, circularity assessment metrics must also consider the inclusion of biological materials for more complex sectors, such as the agro-industrial systems. These systems encompass biological and anthropogenic variables at different scales, in which organic materials and products are returned to the economy. The agri-food sector is the main consumer of freshwater resources in the world and over a quarter of the energy used globally is spent on the production and supply of food (Del Borghi et al., 2020). The application of CE concepts, where conservative practices are implemented between the agro-ecological and agro-industrial subsystems, can mitigate the impact of current industrial agriculture and potentially contribute to the sustainability of the sector. However, although the research progress in the CE field applied to the agri-food sector is constantly evolving, there is no yet a harmonized and shared way of measuring it (Poponi et al., 2022). The scientific literature on LC applications from the CE perspective in the agri-food sector points out how LC methodologies are not fully implemented to provide an overall measure of circularity. Almost all studies focus on the single circular strategy limiting the evaluation to the impacts of the single process or co-products. In life cycle modelling, the most common approach involves structuring the "cycle" along a substantially "linear" pattern extended from cradle to grave (Stillitano et al., 2021). As previously stated, life cycle assessment from a circular perspective should instead consider multiple life cycles within the boundaries of the analysis (cradle-to-cradle approach).

These gaps in scientific literature led us to propose the following research question: How can LC methods measure the effects of closed-loop pathways? In answer to this inquiry, the present contribution provides a proposal of a customized life cycle framework adapted to evaluate circular economy strategies, by including biological cycles and being able to capture all sustainability dimensions. Therefore, we propose a model with expanded assessment boundaries, including co-products valorisation, into a multiple life cycle perspective (cradle-to-cradle), in an attempt to internalize circularity impacts. For example, it will be evaluate the use of by-products as fertilisers by assessing the impact of chemicals replacement. This approach will allow for the evaluation of the environmental, economic, and social effects over time of adopting circular economy strategies. The time horizon is extended for more years following the characteristics of the biological cycles involved and the circular technologies considered, which also means including in the assessment all those cycles and sub-cycles connected with each other. The LC framework here proposed is based on the LCA, the Environmental LCC (ELCC) in terms of internal and external costs, and the SLCA in terms of Psychosocial Risk Factor (PRF) impact pathway. The model is conceived to be tested on the olive-oil sector, with the aim to implement the LC approaches in the agro-ecological (olive growing and harvesting) and agro-industrial (olive-oil extraction) subsystems, which commonly cause significant impacts by generating many by-products whose management is often problematic. Closed-loop strategies within the sector can make it possible to reuse by-products as a possible resource capable to move the system towards a model more sustainable and economically efficient.

To the best of the authors' knowledge, this is the first study attempting to model a cradle-to-cradle life-cycle perspective by using epistemologically aligned life cycle tools. The findings of this study could offer guidance for life cycle scholars and practitioners and help to legitimate firms' circularity claims. Future research will be aimed at validating the applicability of the model on olive-oil farms, to assess the impacts of circularity practices including by-product valorisation.

The paper is structured as follow. Section 2 presents a recent literature overview on LC applications for assessing the sustainability of circular strategies in the agri-food sector. Section 3 introduces the olive-oil sector in terms of sustainability concerns and the mainstream approach for circular life cycle modelling. Section 4 illustrates a new proposal for a customized multi-cycle model in the olive-oil supply chain, and Section 5 argues on the main advantages and limits of the model proposed and concludes the discussion with proposals for further research.

2. Methodological advances in circular pathway assessment by Life Cycle tools focusing on the agri-food sector

In the following sections, an overview of the current methodological advances in circular pathway assessment by LC tools is reported (Table 1).

2.1. Life Cycle Assessment (LCA)

Circularity indicators, such as the most widely used of them, the Material Circularity Indicator (MCI) by the Ellen MacArthur Foundation (2015), focus their analysis on material flows occurring in relation to a process or a product, on a microeconomic scale, or in relation to a supply chain or an economic sector, on a meso- or macroeconomic level. The limitation lies in neglecting the nature of the materials in circulation (e.g., biological material or technical material) and above all in not considering the impacts generated by circular strategies, in environmental, economic, and social terms.

To overcome these limitations, as highlighted by Goddin et al. (2019), circularity assessment finds its methodological complement in life cycle management tools. Environmental Life Cycle Assessment (LCA) has been the spearhead for the development and diffusion of Life Cycle Thinking (LCT), awakening with force interest also in long-established methodologies such as life cycle costing, used since the 1950s in investment appraisal (Strano et al., 2013). Standardized almost twenty-five years ago, LCA methodology has undergone a process of consolidation from the original norms (ISO, 1997), through a first substantial (ISO, 2006a; ISO, 2006b) and after a minor revision (ISO, 2018), to the latest update (ISO, 2021a; ISO, 2021b) that has overhauled both the methodological framework as well as the requirements and guidelines for its application.

The picture is even more complex if one focuses on biological processes. The agri-food sector is certainly one of the most interested in the development of circular strategies and therefore measuring the circularity of these becomes a fundamental requirement (Chiaraluce, 2021; Roos Lindgreen et al., 2021). However, many open questions are still not immediately reflected in circularity assessment methods. The attribution of material flows to the product may be simple for a brick

Table 1
Overview of recent literature on LC applications for assessing the sustainability of circular strategies in agri-food sector.

Authors	Field of application	Circularity topics	LC methodologies			LC approach used	Circularity degree assessment metrics
Albizzati et al. (2021)	Food waste	Waste valorisation	LCA	CLCC/ SLCC	–	- Consequential LCA - Budget costs - Transfer - Externalities by De Bruyn et al. (2018); Friedrich and Quinet (2011); Martinez-Sanchez et al. (2016)	–
Albuquerque et al. (2019)	Food packaging	Reduction	–	ELCC	–	- PSILA life cycle analysis - Externalities by Miah et al. (2017)	–
Aranda et al. (2021)	Meat supply chain	Waste valorisation	–	–	SLCA	- Product Social Impact Life Cycle Assessment (PSILCA) - Eora Database	–
Blanc et al. (2019)	Bio-based plastics in the fruit chain	Remanufacture and regeneration	LCA	CLCC/ SLCC	–	- LCA by ISO standards 14,040:2006 and 14,044: 2006 - Conventional costs - ExA (externality assessment) model	–
El Wali et al. (2021)	Phosphorus supply chain	Recycling	–	–	SLCA	UNEP (2020)	Material Flow Analysis (MFA)
Estévez et al. (2022)	Urban farming	Nutrient recovering	LCA	ELCC	–	- LCA by ISO standards 14,040:2006 and 14,044: 2006 - Internal costs as Capex (capital expenditures) and Opex (operating expenses) - Externalities by De Bruyn et al. (2018) - Total costs by Net Present Value (NPV)	–
Mayanti and Helo (2022)	Agricultural plastic waste	Recycling	LCA	ELCC	–	- Consequential LCA - Budget costs - Transfer cost (excluding externalities)	–
Niero and Hauschild (2017)	Beverage packaging sector	Collection and recycling	LCA	ELCC	SLCA	- Life Cycle Sustainability Assessment (LCSA) - Cradle-to-Cradle (C2C) design framework	Material Circularity Indicator (MCI)
Rufí-Salís et al. (2021)	Rooftop greenhouse	Nutrients recirculation and material recycling	LCA	–	–	Attributional LCA	Material Circularity Indicator (MCI)

Source: Authors' elaboration.

(or for any product resulting from an industrial process), but not at all for an agricultural product. For instance, what proportion of nutrients incorporated into finished products comes from fertilisers applied and what from natural processes? What part of product is strictly linked to cultivation techniques and which one to biological phenomena such as photosynthesis? Is it useful to consider indicators such as lifespan or intensity of use of a product that has a natural shelf life and is inevitably consumed/exhausted during use? On these and other questions the scientific community is debating, trying to find computational solutions that allow an assessment of circularity and environmental impacts using available tools (Rufí-Salís et al., 2021).

In recent years the LCA applications to assess impacts of circular strategies, also in the agri-food sector, have skyrocketed, however, most of the applications are limited to assessing only the environmental aspects of new technologies or new "circular" management systems, leaving the assessment of circularity, through the implementation of specific indicators such as the MCI, out of the objectives of the study. Other studies try to combine the LCA methodology with other customary methodologies such as "Material Flow Analyses" combined with life cycle studies, to provide an assessment of how a product's materials circulate (Stillitano et al., 2021).

Some studies limit the boundaries of the system only to the evaluation of the reuse or recovery process of a waste (e.g. Benalia et al., 2021) and this could allow the analysis of possible burdens shifting. However it does not allow to understand to what extent the valorisation of waste can contribute to improving the circularity of the production process that generated it or of the production process that will benefit from its valorisation. Apart from purely applicative studies, which are often affected by the aforementioned problems, there is a growing interest in the scientific community in more methodological issues, aimed above all at identifying possibilities for integrating life cycle analysis and circularity assessment methodologies, combining the potential of the two approaches in guiding the ecological transition (Peña et al., 2021). The main issue addressed in these studies is represented by the convergence of the concept of "life cycle" that, while in the usual definition of LCA has a "beginning" and an "end", in the concept of CE itself refers to a continuous or closed life cycle, which is configured as an unceasing process of production, recycling and reuse. Obviously, this represents a generalisation, and many questions remain open; as highlighted by Niero and Hauschild (2017) it is not effortless to define at which level, to what extent and from which perspective these loops should be closed.

2.2. Life Cycle Costing (LCC)

LCC is a method for evaluating the economic dimension of sustainability of a product or service, in which monetary costs across its entire life cycle are accounted. There are three types of LCC: i) Conventional LCC (CLCC), also called financial LCC that is synonymous with the total cost of ownership (TCO). CLCC takes into account stakeholders such as consumers, manufacturers, or project managers who are only interested in analysing the cash flows they directly incur; ii) Environmental LCC (ELCC) where, in addition to the direct monetary flows of the product or service, the monetary value of the externalities (environmental impacts) may also be included. Results of ELCC can be useful for all stakeholders in the value chain or life cycle; iii) Societal LCC (SLCC) that includes the monetary value of externalities corresponding to environmental and social impacts and it should have interesting implications for stakeholders working in the government and other public authorities (Kerdlap and Cornago, 2021). Within the international scientific debate on sustainability assessment, ELCC has long attracted great interest. It has been defined as the logical counterpart of LCA analysis for economic evaluation, which goes beyond mere cost accounting and is entirely compatible with LCA (Klöpffer and Renner, 2008). ELCC allows for the estimation of external costs which are the equivalent monetary values of indirect damages that are not explicitly captured in the market (goods or services without a market). For this component, in 2011 a specific guideline was developed to build consensus for achieving an international standard that is comparable to the LCA's ISO standards. Since both tools consider a life cycle thinking perspective and LCA is well established, it made sense to use the LCA framework when specific guidelines for LCC studies are not available (Swarr et al., 2011). Thus, LCA-LCC integration is accomplished by adopting a common database, considering the same functional unit and system boundaries, and following the same methodological steps. Although the use of such a structure does not guarantee synergy as debated by Heijungs et al. (2013), given the lack of standardization for the integration of LCA and LCC, this practice offers the opportunity for closer alignment between these tools (Rödger et al., 2018).

LCC methodology can be applied to support economic decision-making for products and services in a circular economy. Although activities such as reuse and recycling take place in a circular economy as opposed to a traditional linear economy, the way they are accounted for as costs and revenues in an LCC is not so different. While the main circularity indicators are essentially based on the increase in the utility of resources within an economic model, an approach that assesses the life cycle value flows of a product, process or system is an important complement to both circularity and sustainability assessment. As argued by Bradley et al. (2018), CE and closed-loop can drive new sustainable innovations and an LCC model is needed to achieve a truly sustainable progress. In the context of a circular economy, several scholars attempted to use the CLCC, SLCC and ELCC approaches (Kerdlap and Cornago, 2021). For example, about applicative studies in the agri-food sector, Blanc et al. (2019) and Albizzati et al. (2021) performed the CLCC and SLCC, combined with LCA, to provide critical insights into process performance, giving a platform for more targeted technology optimization. The former analysed conventional costs from cradle-to-grave of bio-based plastics in the raspberry supply chain, followed by an estimate of externalities by using ExA (externality assessment) model to assess the social aspects of the analysed scenarios. In accordance with the authors' statement, several are the limitations in LCC processing. Surely, among all emerges the high uncertainty due to the many assumptions and estimates to be taken into account when a real case is applied. To reduce the imprecision of estimates the use of primary data, collected directly in companies, minimizes the margins of error. In our opinion, a sensitivity analysis (missing in the study) exploring the effects on outcomes of changes in the technologies used could strengthen the interpretation of the results. The authors highlighted that the use of bio-based plastics, although it leads to increased costs, contributes to the transition towards a value chain with a low impact on society. Albizzati et al. (2021) calculated budget costs expressed in shadow prices and transfers in factor prices as considered in CLCC, and budget costs and externalities expressed in shadow prices as in SLCC for evaluating the socio-economic sustainability of high-value products obtained from mixed food waste as a feedstock. As argued by the scholars, the implemented LCC model can be a powerful tool to identify environmental and economic hotspots and improve system-level outcomes, avoiding future impacts. To account for the low level of technological readiness that characterizes the technologies analysed, the authors performed extensive uncertainty and sensitivity analyses in order to establish critical points and identify the most uncertain parameters. These were identified in steamand ancillary materials consumption, and feedstock-to-product yield. A broader approach can be found in studies that combine environmental and economic aspects by using LCA and ELCC. In terms of ELCC aligned with LCA analysis, the study proposed by Mayanti and Helo (2022) highlighted the importance of integrated environmental and economic assessment as a key to improve decision-making also in a circular economy environment. The scholars used ELCC in terms of budget costs and transfer cost (excluding externalities) by employing the same assumptions and physical parameters of LCA, to evaluate the environmental and economic implications of bale wrap films collection from the agricultural sector. As parameters, functional unit and system boundaries influence the results of LCA and LCC, agreeing with Mayanti and Helo (2022), using average conditions and a common evaluation method could be a useful compromise. A reliable perturbation analysis showed that LCA and LCC are more sensitive to parameters primarily associated with the market substitution factor and material loss during the recycling process. Reliance on secondary data for most of the processes and data uncertainty are the main shortcomings highlighted in the study. Based on integrated life cycle analysis, Albuquerque et al. (2019) conducted a cost analysis by combining the product structure based integrated life cycle analysis (PSILA) and externalities by Miah et al. (2017), for evaluating the benefits of closed-cycle food packaging systems. A strength of this study is the use of the PSILA method, a technique developed to address the shortcomings of LCC methods in integrating the product life cycle into closed-loop systems. This technique enables the distribution of the closed-loop manufacturing system of high complexity into smaller subsystem models, while also allowing closed-loop costs to be captured in the end-of-life phase. However, a limitation of this method emerges given the failure to account for the cost of logistics transportation and the impact on CO2 emissions. The authors concluded that the LCC approach is a useful economic model to guide the solutions for sustainable manufacturing and the CE vision. In the study by Estévez et al. (2022), an economic evaluation of wastewater management systems to recover nutrients to be used for growing vegetables was carried out by using an ELCC with the estimation of internal costs as Capex (capital expenditures) and Opex (operating expenses), and external costs through the environmental prices provided by De Bruyn et al. (2018). This study confirms the validity of monetizing environmental impacts from LCA results, reporting the conversion of the physical environmental impacts into financial ones. The implementation of the net present value analysis to assess the affordability of the technologies used has, in our view, further strengthened the importance of the study.

2.3. *Social Life Cycle Assessment (SLCA)*

Social Life Cycle Assessment (SLCA) is the latest LC tool in chronological order; it has been developed to evaluate the social impacts occurring during the life cycle, but it is still not consensually defined, and its process of development is being particularly long and difficult. According to Iofrida et al. (2018a, 2018b), in the process of transposing the impact evaluation method to social impacts, some of the typical elements and procedures of environmental LCA were difficult to hand over, such as choosing the functional unit, defining the system boundaries, setting the cut-off criteria.

Essentially, the intrinsic characteristics of social phenomena are very different from those of natural phenomena. Natural phenomena are studied within the realm of post-positivism research paradigms, which recognize that there is a single reality, which can be quite fully explained using cause-effect relationships, obtaining objective and statistically valid data. Differently, social sciences are multiparadigmatic, and the most diverse epistemological positions are possible (Iofrida et al., 2018a; Saunders et al., 2019).

The epistemological eclecticism of social sciences had repercussions on SLCA literature, leading to diverse methodological approaches proposed in the last years for SLCA, because of its roots in the cultural and scientific heritage of sociology and management sciences. Recently, UNEP (2020) updated the Guidelines for SLCA, providing some guidance for SLCA practitioners. According to the Guidelines, there are two main families of Social Life Cycle Impact Assessment (SLCIA) approaches, each of them responding to different practitioner aims: the Reference Scale Approach (Type I or Reference Scale impact assessment), and the Impact Pathway Approach (Type II or Impact Pathway). Therefore, in SLCA, both interpretivist and post-positivist epistemological positions are possible (Iofrida et al., 2018a), with the first one evaluating (mostly in a qualitative and normative way) a wide range of impact categories mostly linked to companies' behaviour (e.g., child labour, corruption, fair salary, etc.), and with the second quantifying cause-effect relationships between life cycle functioning and Areas of Protection in an objective and generalizable way. More in details, type I SLCA studies, principally, apply qualitative and static indicators and advocate for stakeholder participation and social values, they compare the behaviour of the companies to a benchmark, and are more context-bound (Iofrida et al., 2018a). Methods such as PSILCA (Product Social Impact Life Cycle Assessment) and the SHDB (Social Hotspot Database) describe social impacts at the country level, data are aggregated and only show averages across different sector and countries, limiting the possibility to distinguish between alternative operations and locations (Du et al., 2019) and also limiting the possibility to . Conversely, type II SLCA studies are inspired to the post-positivism paradigms because referring to impact pathways, cause-effect relationships, and quantifiable consequences: quantitative methods are mainly applied, supported by mathematical and statistical relationships (Iofrida et al., 2018a).

Recently, some authors analysed how the social dimension of sustainability is considered in circular economy studies, highlighting how social implications are the most disregarded aspect, especially in applicative studies (Geissdoerfer et al., 2017; Moreau et al., 2017; Merli et al., 2018; Schroeder et al., 2019; Padilla-Rivera et al., 2020; Walker et al., 2021; Mies and Gold, 2021).

Geissdoerfer et al. (2017) highlighted that the environmental performances of CE attracted most of the attention of scholars, avoiding a (necessary) holistic perspective of sustainability, focusing the attention on minimising resources input, waste, and emissions, which is an oversimplification of the CE concept. This narrow perspective is even more limited when concerning the social dimension (social well-being, quality of life) in many CE studies: very often social aspects are briefly considered, referring most of the times to impacts on occupation, human health, suggesting that it is not clear how CE could contribute to the improvement of social impacts (Geissdoerfer et al., 2017). This has been confirmed by Moreau et al. (2017), claiming that an analysis of the social and institutional conditions would be of utmost importance to the development of the CE, because also social processes are connected with material and energy flows (Cohen-Rosenthal, 2004).

Social Circular Economy (2017) published a report in which social CE is described as the combination of circular business models (closed-loop production systems) and social enterprises, i.e., firms with a social mission. Therefore, from this source, social CE is considered an effective model to ensure that the economic activities do not harm society or the environment and an operative solution to meet more SDGs at once instead of just the responsible consumption and production, which is met by the CE alone.

However, there is no consensus about how, in practice, social aspects should be considered into CE studies (Padilla-Rivera et al., 2020). Even the Ellen MacArthur Foundation (2015), who is considered one of the main references for a long time, did not report how to measure social issues and how to incorporate these issues into circularity indicators. In a systematic literature review, Padilla-Rivera et al. (2020) found that, in terms of tools and metrics used for social dimension within CE, SLCA can be used to include social aspects of goods and services within a life cycle perspective, to complement environmental and economic dimension of CE.

Concerning applicative studies about social CE in the agricultural sector, very few papers have been published, but the reference to the circular economy consists mainly of a general framework. Aranda et al. (2021) analysed the social impacts of the meat supply chain to prove the versatility and utility of SLCA (PSILCA database) to help companies quantifying and understanding their social performance from a holistic point of view through different social indicators assessed from a life cycle perspective. The study by El Wali et al. (2021) focuses on the issues related to the social sustainability of circular phosphorus economy at regional and global scale, addressing some of the SDGs linked to global phosphorus management. The authors showed that the circular production model contributes to reductions in poverty in middle and low-income regions and it aims to sustain water with a 53 % savings worldwide.

Finally, Mies and Gold (2021) confirmed that the social dimension is poorly addressed in literature, in favour of economic and environmental evaluations; and, despite the availability of specific tools such as SLCA and social organizational LCA (SOLCA), they are not sufficient because they mainly focus on workers and health-related issues. However, this is not fully correct, because many different methodological approaches are currently possible for SLCA, making it an instrument adaptable to a wide range of situations and social issues that affect multiple actors along the value-chain.

3. The olive oil supply chain

3.1. Major sustainability concerns of the agro-industrial phases in the olive-oil sector

With a total area of around 11 million ha, the Mediterranean basin provides about 95 % of the worldwide olive production (FAOSTAT, 2020). The olive oil sector is thus a significant source of income, but it is also one of the main consumer of resources and producer of wastes both in the olive cultivation phase (wood, branches, and leaves) and the processing phase (olive pomace, olive mill wastewater, and olive stones). Only in European producing countries, there are about 9.6 million tons year^{-1} of wastes from the oil mills and 11.8 million tons of additional biomass from the olive pruning process (Berbel and Posadillo, 2018). These wastes, if not properly managed, have a high environmental impact and high costs. Careful management can turn into a benefit for the company in socio-economic terms and environmental impact by being part of the circular economy strategies.

As with other crops, several environmentally harmful issues emerge from the olive cultivation phase. About the core process, among the main environmental and ecological concerns facing agricultural operators, the soil management, in particular with mechanical processes and the chemical control of weeds, is responsible to generate mainly compaction, oxidation of organic substance, destruction of wildlife shelters, pollution of surface and groundwater. Nutrition management, if not properly performed, leads to nitrate and phosphorous leaching, and eutrophication of water (Rodrigues et al., 2019), alterations in soil pH and cation exchange capacity. Mismanagement of canopy can lead to a higher incidence of phytosanitary diseases and vegetative-productive imbalances. Incorrect use of phytosanitary products results in drift with pollution of surface and groundwater, accumulation of heavy metals, reduction of biodiversity, including useful fauna (Calatrava et al., 2021). By way of example, olive harvesting, if mechanically carried out, can lead to phenomena of soil compaction, destruction of shelters for wildlife, and high spread of fungal diseases. Concerning irrigation, which is mandatory in super-intensive plants, the high use of water and the risk of salinization of the soil are, certainly, among the main concerns.

The extraction phase of olive oil generates by-products that, due to their high phytotoxicity, can have a high polluting load, threatening the fertility of the soil and the potability of the aquifers. The quantity and physico-chemical properties of the by-products produced depend mainly on the technological method used for extraction. In fact, according to the most common extraction methods to date, it is possible to distinguish the following typologies: traditional production process producing for a ton of olives between 400 and 600 kg of olive mill wastewater; three-phase production process between 1000 and 1200 kg of wastewater; and two-phase production process, which does not produce vegetation water but pomace with high moisture content. Mill wastewater has a high organic load and numerous contaminants (phenolic compounds), which are phytotoxic and poorly biodegradable

(Ergüder et al., 2000; Vlyssides et al., 2017). The pomace of the three-phase plants having a low water content can be used for the extraction of pomace oil or sprinkled on agricultural land according to the regulations in force in each country. The wet pomace from the two-stage extraction, on the other hand, has a strong odour and a pasty consistency, making it difficult to manage and transport it.

In addition to the environmental issues, several concerns can affect the socio-economic performance of the olive oil sector, which may depend on the planting system (traditional, intensive, and super-intensive), the farming systems (organic and conventional), the productivity, the level of mechanization, the investments, and the management costs. In terms of economic impacts, the highest costs concern the productive means and the labour, above all in the traditional plants, hill scenarios, and in the farms characterized by a low level of mechanization (Bernardi et al., 2018, 2021). The social impacts may relate to the hours of potential exposure of workers to working conditions that can lead to health problems, the level of employment in this sector for rural populations as a significant source of income, as well as the maintaining the cultural landscape and identity (Iofrida et al., 2020).

3.2. *Mainstream approach for circular life cycle modelling in the extra virgin olive oil production*

The modelling of the life cycle is the cornerstone of a life cycle assessment and, the most commonly used approach involves structuring "the cycle" along with a substantially "linear" scheme that extends from the cradle to the grave of the product. All input and output flows will be referred to the main product, so the management of co-products in the modelling process may follow two different approaches: one, the most widespread, which foresees the definition of an allocation criterion to the co-product of the input and output flows (e.g., economic, or energy); the other which avoids the use of allocation criteria favouring the expansion of the system. This type of modelling is generally based on the attribution of a certain amount of avoided impacts by the production system, thanks to the substitution of some material or energy with the products of the by-product valorisation (e.g., if the co-product will be used to produce energy, the impacts related to the production of energy from fossil fuels will be avoided) (Houssard et al., 2021). Waste generated during the production process is generally considered as a "zero burdens" output product (cut-off approach) or they can be considered in an expansion approach if there is a process of enhancing those (Malabi Eberhardt et al., 2020). This last aspect is particularly connected with the evaluation of circular strategies that can also be based on the saving of raw materials or the improvement of the product in terms of its useful life or intensity of use. However, it also true that in most cases these strategies are based on the valorisation of waste, transforming it into co-products through techniques that foresee its reuse or recycling.

Fig. 1 shows the mainstream approach for circular life cycle modelling for the extra virgin olive oil (EVOO) production, where the cycle is designed according to a linear scheme. It is possible to distinguish the different phases of production: *i*) agricultural production (upstream processes), *ii*) industrial extraction of EVOO and bottling (core processes), and *iii*) distribution, selling and consuming (downstream processes), from which various by-products are obtained. The main by-products of the agricultural phase are the pruning biomass, which in the context of traditional management is burned in the field (Michalopoulos et al., 2020), with high environmental impacts due to the production of CO_2 (Perone, 2019). Its reintroduction during the agricultural phase by shredding could represent an efficient CE approach. This is a good source of organic substance that through natural mineralization can replace a part of chemical fertilisers. In the industrial processing phase, the following by-products can emerge: leaves obtained from the olive cleaning, vegetation water obtained from the olive washing and the separation phase, pomace (with high water content in two-phase mill), and olive stones. CE approaches could be the use of vegetation water after a settling period as irrigation water for the agricultural phase, the use of decomposed leaves as an organic soil improver, the use of olive pomace and olive stones as fuel to obtain the thermal energy needed for the processing plant (Benalia et al., 2021) or as organic fertilizer after a composting process. Moreover, considering the bottling phase, the possibility of recycling olive oil empty bottles would allow a great saving in environmental terms.

To our best knowledge, all recent studies from literature seeking to apply LC tools to assess the sustainability performance of circular strategies implemented along the olive oil supply chain seem to follow traditional linear schemes for life cycle modelling (from cradle to grave). For example, a "cradle-to-grave" approach was used by Pampuri et al. (2021) to perform an LCA analysis for assessing the environmental impact of lab-scale food preparations enriched with phenolic extracts from olive oil mill wastewater and olive leaves. Espadas-Aldana et al. (2021) and Uceda-Rodríguez et al. (2021) applied a "cradle-to-gate" ap-

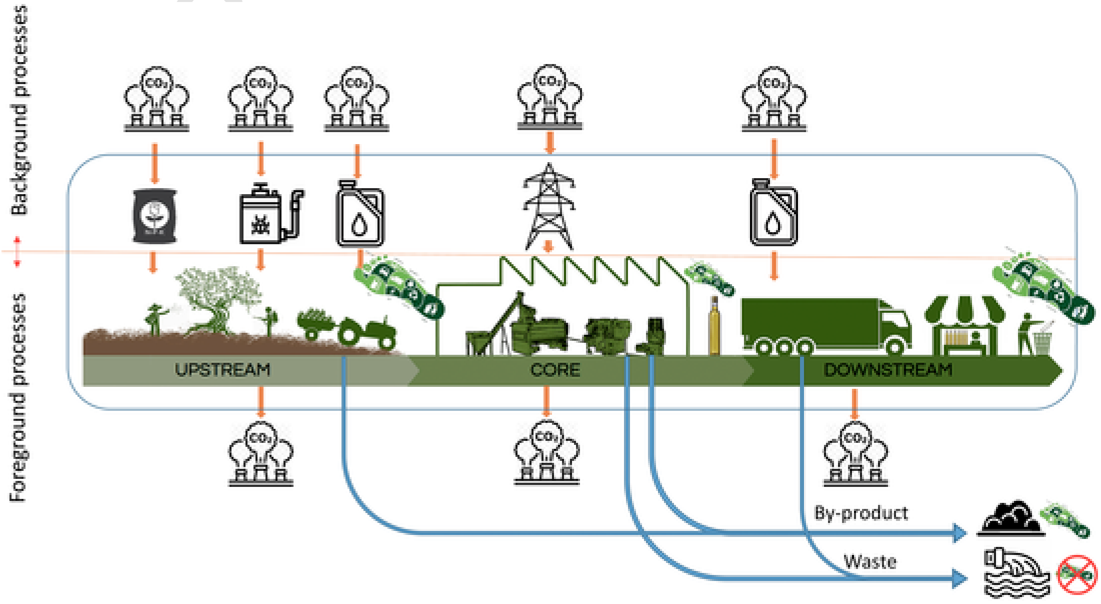

Fig. 1. Mainstream approach for circular life cycle modelling in the EVOO production (Source: Authors' elaboration).

proach life cycle assessment to evaluate the environmental benefits related to the olive pomace valorisation, as reinforcement in polymeric biocomposite materials and as an additive in the manufacture of lightweight aggregates, respectively. A similar approach has also been applied by Nikkhah et al. (2021) and Silvestri et al. (2021), who performed an LCA analysis to evaluate environmental impacts of olive kernel oil production systems and reuse systems of olive mill wastewater for the fired clay brick production, respectively.

4. A proposal of a customized multi-cycle model in the olive-oil supply chain

Deepening the knowledge developed in the context of the evaluation of remanufacturing and recycling processes, it is possible to find references of a modelling approach that allows going beyond the classical concept of a "cradle-to-grave" life cycle to a broader "cradle-to-cradle" model (Suhariyanto et al., 2017). In particular, through the 6Rs (Reduce, Reuse, Recycle, Recover, Redesign, and Remanufacture) concept, it can be devised a life-cycle model based on a *"perpetual material flow in a sustainable multiple product life-cycle system"* (Jaafar et al., 2007: 37). This approach takes the form of a Multi-Life Cycle Assessment, which consists of considering multiple life cycles within the boundaries of the analysis. This modelling approach has not been widely accepted due to the complexity of carrying out such an extensive analysis, and few papers explicitly mention a multi-cycle approach (Suhariyanto et al., 2017). However, the increasing focus on the evaluation of circular economy strategies has given this approach a new lease of life, by addressing one of the main issues related to the interpretation of the concept of life cycle by circularity assessment models. Thus, in recent years, some studies have been published proposing the application of a Multi Life Cycle Assessment to assess circularity scenarios (e.g., Niero and Olsen, 2016; van Stijn et al., 2021). However, all the studies identified in the literature relating to multi-cycle applications have a technical cycle as the object of analysis(aluminium cans, engine components, building components ecc.), citing the nomenclature used by The Ellen MacArthur Foundation in the butterfly diagram.

Considering that, this study aims to propose a multi-cycle modelling approach for the environmental, economic, and social evaluation of a product, adapting it to biological cycles. A life cycle analysis of the EVOO production will be carried out, following the requirements and guidelines for life cycle analyses (ISO, 2021b).

4.1. Methodological steps

Guided by the principles of transparency and repeatability of results, LCA is based on an accounting of material and energy input and output of the product life cycle, from the extraction of raw materials to the use phase of the product and its disposal at the end of its function. The ISO 14040 standard (ISO, 2021a) defines four distinct phases of an LCA: Goal and scope, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and Interpretation. These phases follow an iterative scheme whereby one phase interacts with the other and is interdependent. Basically, the Goal and Scope phase defines the characteristics of the model that will be represented in the next LCI phase and that will be assessed and interpreted in the LCIA and Interpretation phases. The ELCC and SLCA approaches here proposed are meant to be aligned with the ISO 14040 and 14,044 for LCA and follow the same steps (Table 2).

4.1.1. Goal and scope

The first phase of the analysis includes the definition of the objective and scope. The function of the system under study is the production of Extra Virgin Olive Oil (EVOO), therefore the Functional Unit (FU) chosen will be 1 Litre of EVOO.

The crucial issue will be the definition of the system boundaries, and in particular, the life cycle model is based on the interdependent evaluation of different life cycles. The extension of the system boundaries to several production cycles, enables to consider a closed-loop system for all intents and purposes - in a cradle-to-cradle perspective. Even if the distribution, use and disposal phases of the product are excluded from the analysis, valorisation and/or recycling of cultivation and processing wastes are included in system boundaries. It can be reused in the next cycle or other production cycles, generating a reduction in the flow of virgin material from the second cycle onwards. The prerogative to consider within the system boundaries also the processes of waste valorisation allows taking into account possible burden shifting (Fig. 2).

Table 2
The methodological framework of the multi-cycle model.

ISO 14040-44 (2021) phases	LCA	ELCC	SLCA
Goal and scope	Functional Unit: 1 Litre of EVOO; System boundary: multiple cycles in a cradle-to-cradle perspective; Allocation procedure: mixed approach/System Boundaries Expansion with substitution (SBES).		
Life Cycle Inventory (LCI)	Primary data: farm-based data sources. Secondary data: Ecoinvent, Agri-footprint, and World Food LCA databases; IPCC (2019) for the estimate of N_2O, Brentrup et al. (2000) for the estimate of nitrate leaching, etc.	Primary data: farm-based data sources. Secondary data: public databases, indirectly derived data (i.e., surveys and interviews, and expert opinions); data from LCA results and Environmental Prices Handbook (De Bruyn et al., 2018).	Primary data: farm-based data sources. Secondary data: literature studies.
Life Cycle Impact Assessment (LCIA)	ReCiPe (Huijbregts et al., 2017) assessment method using SimaPro software.	Internal costs: specific economic and physical parameters to calculate each cost; Investment analysis. External costs: Environmental Prices approach (De Bruyn et al., 2018) using SimaPro software.	Type II: PRF Impact Pathway using SimaPro software.
Interpretation	Retrieving conclusions and recommendations from results		

Source: Authors' elaboration.

The multi-cycle model, in fact, includes within the system under study also the processes of valorisation of co-products and waste, thus making it possible to assess all the impacts generated for their valorisation within the boundaries of the system. In this way, for example, the substitution of fertilisers will not simply be considered as an avoided impact, but the impact of its replacement will be evaluated.

Another factor to be taken into account will be the procedures for attributing impacts to co-products are also a crucial issue to take into account in order to evaluate the multi-cycle scenarios. In this proposal, an effective mixed approach provides for an allocation system for the co-products whose secondary life cycle is interconnected to re-use/recycling processes within the system boundaries (e.g., exhaust pomace), while a System Boundaries Expansion with Substitution (SBES) approach will be considered for those co-products whose secondary life cycle will not be interconnected to re-use/recycling processes within the system boundaries (e.g., extraction of polyphenols from leaves). Through this approach, it is assumed that the co-products generated will be able to substitute other products on the market, and therefore the impact generated by the production of these products is considered avoided. If, for example, renewable energy is produced from a co-product, the impacts of the equivalent amount of non-renewable energy that the former will replace on the market can be considered avoided.

4.1.2. Life Cycle Inventory (LCI)

The second step is the creation of the Life Cycle Inventory (LCI). In this regard, it should be specified that the results of the inventory analysis are also used to define the incoming and outgoing material flows and

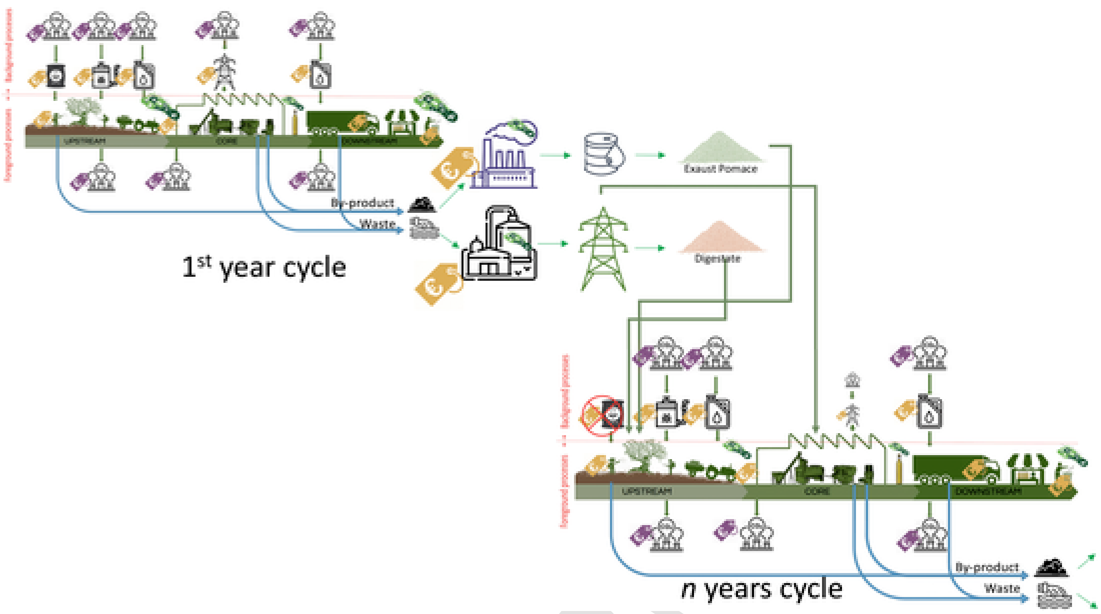

Fig. 2. Design of the multi-cycle model to assess circularity pathways in olive-oil chain (Source: Authors' elaboration).

therefore to measure circularity. For the LCA analysis of multi-cycle scenarios, the availability of the widest possible amount of primary data is of utmost importance, with secondary data obtained from the most comprehensive life cycle inventory databases (e.g. Ecoinvent; Agri-footprint; World Food LCA Database), while data relating to emissions generated during production processes and waste and co-product valorisation will be estimated using specific consolidated estimation models, e.g., IPCC (2019) for the estimate of N_2O, Brentrup et al. (2000) for the estimate of nitrate leaching etc.

To accomplish a believable LCC analysis, the accessibility of reliable cost data is crucial. Farm-based data sources, independent data sources (i.e., public and updated statistical databases) and derived data by surveys and interviews, and expert opinions are useful for carrying out the inventory of internal costs, and in particular, also for materials and energy consumption production-related relying on the LCA's inventory analysis. However, the production data are expanded to cover all costs (investment costs, labour costs, and other overhead costs). Data for evaluating external costs are derived from LCA results and Environmental Prices Handbook (De Bruyn et al., 2018).

Concerning the SLCA's inventory analysis, the hours of exposure for each life cycle phase and task (such as planting, pruning, harvesting, input supplying, etc.), classifying the typology of exposure (manual or mechanical work, temperature, exposure to pesticides, noise, etc.) are scrutinized by conducting a scientific literature review on particular working, consuming and living conditions that entail exposure to psychosocial risk factors. Each verified statistical association retrieved from verified sources is classified according to its intensity.

4.1.3. *Life Cycle Impact Assessment (LCIA)*

The assessment of environmental impacts for this multi-cycle proposal will be performed using the ReCiPe (Huijbregts et al., 2017) assessment method, midpoint and endpoint version, for covering the characterization of impacts as well as the contribution analysis of individual processes within a cycle and individual cycles within the multiple cycle systems (Goedkoop et al., 2013).

From the economic characterization, we will consider the ELCC methodology aligned with LCA to evaluate internal and external costs of the circular olive-oil system under study. Internal costs include the initial investment costs, the costs of materials and energy, labour cost, interests, ownership costs of machinery and land investments (i.e., depreciations, insurance, repairs, and maintenance), and administration overheads. To include external costs in an ELCC, the externalities need to be monetized by putting a specific value on the environmental impacts of a product. To date, the main path for calculating externalities and integrating LCA-LCC is to monetise environmental impacts resulting from LCA studies, struggling to translate environmental impacts into economic impacts. Starting from the LCA results obtained, the Environmental Prices approach (De Bruyn et al., 2018), which expresses the WTP for less environmental pollution in Euros per kilogram of pollutant, is applied through the SimaPro software to evaluate external costs. The environmental prices identified in the environmental prices handbook (De Bruyn et al., 2018) provide average values for the EU28, for emissions from an average emission source at an average emission site in the year 2015 and are distinguished on the environmental categories it values (Durão et al., 2019). Finally, the ELCC approach here proposed also envisages an investment analysis to determine the financial performance of the likely technologies involved in the circular scenarios under study. To carry out this analysis, annual cash flows are normally actualised considering the time of occurrence, as well as dynamic criteria like net present value, internal rate of return, and discounted payback period.

Concerning SLCA, the Psychosocial Risk Factor (PRF) impact pathway (Iofrida et al., 2018c; Iofrida et al., 2019) is applied to assess the social impacts of the olive growing production to highlight specific effects (if any) directly linked to the adoption of circular strategies. This methodology allows quantifying the risk of psychosocial impacts on different typologies of stakeholders, according to the duration of exposure to certain living and working conditions that can lead to health issues. Cox et al. (2000) defined PRF as the aspects and characteristics of work planning and management that can potentially lead to physical or psychological damage. Precisely, the psychosocial risks are measured using odds ratios (ORs), a statistical measure of the intensity of association between two variables, e.g., as the ratio between the odds of exposure for people with a disease and the odds of exposure for healthy people (Szumilas, 2010). Data are retrieved from validated scientific investigations, normally clinical and epidemiological validated studies that examined the relationships between specific living and working conditions and diseases (or disorders). For example, low incomes are strongly associated to myocardial infarction and to stroke (Min et al., 2017), the use of organophosphate insecticides increases the risk of Non-Hodgkin's Lymphoma (Kobayashi et al., 2012), and the exposure to sun combined to the use of glyphosate (herbicide) increases the risk of asthma (Salameh et al., 2006).

Measuring the psychosocial risks with the ORs is a retrospective analysis of a phenomenon, expressed with a non-dimensional value, and it can assume values between 0 and $+\infty$: a value of 1 indicates that there is no association between disease and exposure, while values >1 indicate a positive association (the risk factor can provoke the disease/disorder); higher values show a stronger association between exposure and disease (Bottarelli and Ostanello, 2011).

A PRF matrix, where every condition of exposure that occurred in the scenarios is linked, as retrieved from scientific literature to a physical or psychosocial disease is constructed. The assessment of social impacts is then conducted through the quantification of hours when stakeholders are exposed to particular conditions that represent factors of psychosocial risks.

For the first time, an Impact Assessment Method based on PRFs and integrated into Simapro will be proposed to also allow the assessment of the social impacts of the same life cycle model considered for LCA and LCC analysis.

4.1.4. *Interpretation of results*

The results are interpreted through sensitivity analyses related to the variability of material flows within the closed system.

For the environmental part, the effects on results of different allocation approaches and different types of substituted products will be evaluated according to the 'System Boundaries Expansion with substitution' approach, while, for example, in LCC analysis, the timing of costs is very important. As commodity prices are much more volatile due to the market mechanisms of supply and demand, costs with high price variability (e.g., fuel costs) must necessarily be subjected to an in-depth analysis to reduce the uncertainty of results in terms of how much a change of the variables, within a pre-established range, can affect them. Additionally, in cases where there is no single correct discount rate, the effect of different discount rates should be investigated through a sensitivity check.

Concerning social impacts, the sensitivity check aims at determining whether and to what extent the results of social evaluation may be affected by the previous methodological steps and assumptions about data, value judgments, activity variables, calculation of the social performance and social impacts (UNEP, 2020). Many methods and tools to support a sensitivity analysis are available for environmental LCA studies; to some extent these can be applied to S-LCA studies too (UNEP, 2020).

5. Conclusions

Key issues emerge when comparing circularity and life cycle approaches. As previously mentioned, the main concern stays in the different views of the product life cycle. In the case of impact evaluation, the system boundaries focus on a single life cycle of a product (cradle-to-gate or cradle-to-grave analyses); while the circularity evaluation would require a system boundary extension to more life cycles (cradle-to-cradle perspective), to include the reuse of components, their remanufacture and recycling. Therefore, an LC approach complementary to a circularity assessment framework should extend the boundaries of the system in a multi-cycle approach, by integrating into the horizon of the analysis product losses, recycling and reuse in the next cycle, transport, and all processes that allow closing the loop of the LC methodologies according to circular approach.

The assessment of both circularity and environmental, economic, and social sustainability of a system turns out to be even more complex when biological processes are involved. The olive-oil production, which encompasses both biological and technical cycles, is one example. Agricultural process evaluation involves difficulties related to the modelling of phenomena that are not completely under anthropic control. On the other hand, industrial process evaluation involves the difficulties associated with waste and by-product management.

Based on these assumptions, the methodological proposal here shown concerned the design of customized LC modelling, where a circular olive-oil system of more interconnected life cycles is considered into a multi-cycle perspective (cradle-to-cradle), in an attempt to internalize circularity impacts. The model will allow for the evaluation of the environmental, economic, and social effects over time of adopting CE strategies along the entire olive-oil supply chain. In this sense, as example, the impact of chemical fertilisers replacement with by-products will be evaluate within the system boundaries. Specifically, the framework suggests implementing and applying the LCA, the ELCC in terms of internal and external costs, and SLCA in terms of impact pathway assessment to the agro-industrial system, from which many by-products are generated, causing several environmentally harmful impacts, and socio-economic concerns that can affect the performance of the olive oil sector. In this context, closed-loop strategies make potential wastes susceptible to being transformed into by-products, allowing their reuse within the sector or the recycling, enhancing, and adding value to them and moving to more sustainable and economically efficient production and consumption patterns. Indeed, by using specific technologies, it is possible to manage the by-products as a possible resource capable of being converted into a source of income for the company (e.g., energy, organic matter, irrigation water). This could be useful to provide guidelines for olive farmers and entrepreneurs, who want to invest in technological solutions for the management of their by-products to reduce environmental impacts and increase profitability.

The proposed multi cycle model provides significant assets and advantages. First, it allows the application of three epistemologically aligned methodologies, LCA, ELCC and SLCA, able to target an overall sustainability assessment. The multiple cycle approach also makes it possible to highlight burden shifting among life cycle phases, as it consider within the system boundaries the processes of waste valorisation. Our model is designed to be applied to open systems such as agricultural systems, where energy, nutrients, organisms and information constantly cross system boundaries. The multiple life cycle analysis for quantifying net flows among system components and into and out of systems will provide insight into the movements and effects of these processes over the long term. Another contribution of this research is related to the possibility of legitimizing firms' circularity claims, helping to build a framework for developing circular business models.

Future research will be aimed at testing the multi-cycle model here proposed at the micro level to validate its applicability and effectiveness on olive-oil farms, considering that its implementation in the micro dimension can also have extensive effects at the macro and/or *meso* scale. Analysing the model in real case studies is therefore crucial to adapt it to the intrinsic complexity of human activities. Furthermore, for analysing the potential trade-offs, holistic tools such as multi-criteria decision analysis should be used to combine LCA, ELCC and SLCA in order to identify the most effective CE practices in the long term.

Funding

This research was supported by the DRASTIC PRIN 2017 research project (project code: 2017JYRZFF), funded by the Italian Ministry of Education, University, and Research (MIUR-ITA).

Uncited references

CRediT authorship contribution statement

Teodora Stillitano: Conceptualization, Methodology, Writing – original draft. **Giacomo Falcone:** Conceptualization, Methodology, Investigation, Writing – original draft. **Nathalie Iofrida:**

Conceptualization, Methodology, Writing – original draft. **Emanuele Spada:** Methodology, Investigation, Writing – original draft. **Giovanni Gulisano:** Supervision, Writing – review & editing. **Anna Irene De Luca:** Conceptualization, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing, Funding acquisition.

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.

References

Albizzati, P.F., Tonini, D., Astrup, T.F., 2021. High-value products from food waste: an environmental and socio-economic assessment. Sci. Total Environ. 755, 142466. https://doi.org/10.1016/j.scitotenv.2020.142466.

Albuquerque, T.L.M., Mattos, C.A., Scur, G., Kissimoto, K., 2019. Life cycle costing and externalities to analyze circular economy strategy: comparison between aluminum packaging and tinplate. J. Clean. Prod. 234, 477–486. https://doi.org/10.1016/j.jclepro.2019.06.091.

Aranda, J., Zambrana-Vásquez, D., Del-Busto, F., Círez, F., 2021. Social impact analysis of products under a holistic approach: a case study in the meat product supply chain. Sustainability 13, 12163. https://doi.org/10.3390/su132112163.

Benalia, S., Falcone, G., Stillitano, T., De Luca, A., Strano, A., Gulisano, G., Zimbalatti, G., Bernardi, B., 2021. Increasing the content of olive mill wastewater in biogas reactors for a sustainable recovery: methane productivity and life cycle analyses of the process. Foods 10 (5), 1029. https://doi.org/10.3390/foods10051029.

Berbel, J., Posadillo, A., 2018. Review and analysis of alternatives for the valorisation of agro-industrial olive oil by-products. Sustainability 10, 237. https://doi.org/10.3390/su10010237.

Bernardi, B., Falcone, G., Stillitano, T., Benalia, S., Strano, A., Bacenetti, J., De Luca, A.I., 2018. Harvesting system sustainability in Mediterranean olive cultivation. Sci. Total Environ. 625, 1446–1458. https://doi.org/10.1016/j.scitotenv.2018.01.005.

Bernardi, B., Falcone, G., Stillitano, T., Benalia, S., Bacenetti, J., De Luca, A.I., 2021. Harvesting system sustainability in Mediterranean olive cultivation: other principal cultivar. Sci. Total Environ. 766, 142508. https://doi.org/10.1016/j.scitotenv.2020.142508.

Blanc, S., Massaglia, S., Brun, F., Peano, C., Mosso, A., Giuggioli, N.R., 2019. Use of bio-based plastics in the fruit supply chain: an integrated approach to assess environmental, economic, and social sustainability. Sustainability 11, 2475. https://doi.org/10.3390/su11092475.

Bottarelli, E., Ostanello, F., 2011. Epidemiologia. Teoria ed esempi di medicina veterinaria. Edagricole, Milano.

Bradley, R., Jawahir, I.S., Badurdeen, F., Rouch, K., 2018. A total life cycle cost model (TLCCM) for the circular economy and its application to post-recovery resource allocation. Resour. Conserv. Recycl. 135, 141e149. https://doi.org/10.1016/j.resconrec.2018.01.017.

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. LCA 5, 349. https://doi.org/10.1007/BF02978670.

Calatrava, J., Martínez-Granados, D., Zornoza, R., González-Rosado, M., Lozano-García, B., Vega-Zamora, M., Gómez-López, M.D., 2021. Barriers and opportunities for the implementation of sustainable farming practices in Mediterranean tree orchards. Agronomy 11 (5), 821. https://doi.org/10.3390/agronomy11050821.

Chiaraluce, G., 2021. Circular economy in the agri-food sector: a policy overview. Ital.Rev.Agric.Econ. 76 (3), 53–60. https://doi.org/10.36253/rea-13375.

Cohen-Rosenthal, E., 2004. Making sense out of industrial ecology: a framework for analysis and action. J. Clean. Prod. 2, 1111–1123. https://doi.org/10.1016/j.jclepro.2004.02.009.

Corona, B., Shen, L., Reike, D., Carreón, J.R., Worrell, E., 2019. Towards sustainable development through the circular economy-a review and critical assessment on current circularity metrics. Resour. Conserv. Recycl. 151, 104498. https://doi.org/10.1016/j.resconrec.2019.104498.

Cox, T., Griffiths, A., Rial-Gonzalez, E., 2000. Research on Work-related Stress. Office for Official Publications of the European Communities, Luxembourg. doi:http://europa.eu.int.

De Bruyn, S., Bijleveld, M., de Graaff, L., Schep, E., Schroten, A., Vergeer, R., Ahdour, S., 2018. Environmental Prices Handbook EU28 Version. CE Delft.

De Luca, A.I., Iofrida, N., Leskinen, P., Stillitano, T., Falcone, G., Strano, A., Gulisano, G., 2017. Life cycle tools combined with multi-criteria and participatory methods for agricultural sustainability: insights from a systematic and critical review. Sci. Total Environ. 595, 352–370. https://doi.org/10.1016/j.scitotenv.2017.03.284.

Del Borghi, A., Moreschi, L., Gallo, M., 2020. Circular economy approach to reduce water-energy-food nexus. Curr. Opin. Environ. Sci. Health 13, 23–28. https://doi.org/10.1016/j.coesh.2019.10.002.

Du, C., Ugaya, C., Freire, F., et al., 2019. Enriching the results of screening social life cycle assessment using content analysis: a case study of sugarcane in Brazil. Int. J. Life Cycle Assess. 24, 781–793. https://doi.org/10.1007/s11367-018-1490-4.

Durão, V., Silvestre, J.D., Mateus, R., De Brito, J., 2019. Economic valuation of life cycle environmental impacts of construction products - a critical analysis. IOP Conf. Ser.: Earth Environ. Sci. 323, 012147. https://doi.org/10.1088/1755-1315/323/1/012147.

El Wali, M., Golroudbary, S.R., Kraslawski, A., 2021. Circular economy for phosphorus supply chain and its impact on social sustainable development goals. Sci. Total Environ. 777, 146060. https://doi.org/10.1016/j.scitotenv.2021.146060.

Ellen Macarthur Foundation, 2015. Circularity Indicators. An Approach to Measuring Circularity. EMF, Cowes, UK.

Ergüder, T.H., Güven, E., Demirer, G.N., 2000. Anaerobic treatment of olive mill wastes in batch reactors. Process Biochem. 36, 243–248. https://doi.org/10.1016/S0032-9592(00)00205-3.

Espadas-Aldana, G., Guaygua-Amaguaña, P., Vialle, C., Belaud, J.P., Evon, P., Sablayrolles, C., 2021. Life cycle assessment of olive pomace as a reinforcement in polypropylene and polyethylene biocomposite materials: a new perspective for the valorization of this agricultural by-product. Coatings 11, 525. https://doi.org/10.3390/coatings11050525.

Estévez, S., González-García, S., Feijoo, G., Moreira, M.T., 2022. How decentralized treatment can contribute to the symbiosis between environmental protection and resource recovery. Sci. Total Environ. 812, 151485. https://doi.org/10.1016/j.scitotenv.2021.151485.

European Commission, 2020. A New Circular Economy Action Plan for a Cleaner And More Competitive Europe. COM(2020) 98 final. Brussels, 11.3.2020.

FAOSTAT, 2020. Food and agriculture organization of the United Nations. http://www.fao.org/faostat/en/#data/QC. (Accessed 25 January 2022).

Font Vivanco, D., van der Voet, E., 2014. The rebound effect through industrial ecology's eyes: a review of LCA-based studies. Int. J. Life Cycle Assess. 19, 1933–1947. https://doi.org/10.1007/s11367-014-0802-6.

Fortes, C., Mastroeni, S., Segatto, M.M., Hohmann, C., Miligi, L., Bakos, L., Bonamigo, R., 2016. Occupational exposure to pesticides with occupational sun exposure increases the risk for cutaneous melanoma. Occup. Environ. Med. 58 (4). https://doi.org/10.1097/JOM.0000000000000665.

Friedrich, R., Quinet, E., 2011. External costs oftransport in Europe. In: de Palma, A., Lindsey, R., Quinet, E., Vickerman, R. (Eds.), A Handbook of Transport Economics. Edward Elgar Publishing Limited, Cheltenham, UK.

Fritschi, L., Benke, G., Hughes, A.M., Kricker, A., Turner, J., Vajdic, C.M., Fritschi, J., 2005. Occupational exposure to pesticides and risk of non-Hodgkin's lymphoma. Am. J. Epidemiol. 162 (9), 849–857. https://doi.org/10.1093/aje/kwi292.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The circular economy - a new sustainability paradigm? J. Clean. Prod. 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048.

Georgescu-Roegen, N., 1988. The interplay between institutional and material factors: the problem and its status. In: Barriers to Full Employment. Palgrave Macmillan, London.

Goddin, J., Marshall, K., Pereira, A., Herrmann, S., 2019. Circularity Indicators - An Approach to Measuring Circularity. Methodology. The Ellen MacArthur Foundation, Wilmington, UK.

Goedkoop, M., Oele, M., Leijting, J., Ponsioen, T., Meijer, E., 2013. Introduction to LCA With SimaPro. PRè - Product Ecology Consultants, Netherlands.

Heijungs, R., Settanni, E., Guinée, J., 2013. Toward a computational structure for life cycle sustainability analysis: unifying LCA and LCC. Int. J. Life Cycle Assess. 18, 1722–1733. https://doi.org/10.1007/s11367-012-0461-4.

Houssard, C., Maxime, D., Pouliot, Y., Margni, M., 2021. Allocation is not enough! A system boundaries expansion approach to account for production and consumption synergies: the environmental footprint of Greek yogurt. J. Clean. Prod. 283, 124607. https://doi.org/10.1016/j.jclepro.2020.124607.

Huijbregts, M.A.J., Steinmann, Z.J.N., Elshout, P.M.F., Stam, G., Verones, F., Vieira, M., Zijp, M., Hollander, A., van Zelm, R., 2017. ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. Int. J. Life Cycle Assess. 22, 138–147. https://doi.org/10.1007/s11367-016-1246-y.

Iofrida, N., De Luca, A.I., Strano, A., Gulisano, G., 2018a. Can social research paradigms justify the diversity of approaches to social life cycle assessment? Int. J. Life Cycle Assess. 23, 464–480. https://doi.org/10.1007/s11367-016-1206-6.

Iofrida, N., De Luca, A.I., Strano, A., Gulisano, G., 2018c. Social life cycle assessment for agricultural sustainability: comparison of two methodological proposals in a paradigmatic perspective. Ital.Rev.Agric.Econ. 72 (3), 223–265. https://doi.org/10.13128/REA-22801.

Iofrida, N., Strano, A., Gulisano, G., De Luca, A.I., 2018b. Why social life cycle assessment is struggling in development? Int. J. Life Cycle Assess. https://doi.org/10.1007/s11367-017-1381-0.

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 (4), 767-78010-18-1482–4. https://doi.org/10.1007/s11367-018-1482-4.

Iofrida, N., Stillitano, T., Falcone, G., Gulisano, G., Nicolò, F.B., De Luca, A.I., 2020. The socio-economic impacts of organic and conventional olive growing in Italy. New Medit. 19 (1), 117–131. https://doi.org/10.30682/nm2001h.

IPCC, 2019. In: N2O Emissions From Managed Soils And CO2 Emissions From Lime And Urea Application, vol. 4. IPCC, p. 1e54. (Chapter 11).

ISO, 1997. ISO 14040:1997 Environmental Management - Life Cycle Assessment: Principles And Framework. International Organization for Standardization, Geneva.

ISO, 2006a. ISO 14040:2006 Environmental Management - Life Cycle Assessment: Principles And Framework. International Organization for Standardization, Geneva.

ISO, 2006b. ISO 14044:2006 Environmental Management - Life Cycle Assessment: Requirements And Guidelines. International Organization for Standardization, Geneva.

ISO, 2018. UNI EN ISO 14044:2018 Environmental Management - Life Cycle Assessment: Requirements And Guidelines - Amendment 1.

ISO, 2021a. ISO 14040:2021. Environmental Management - Life Cycle Assessment: Principles And Framework. International Organization for Standardization, Geneva. 2021.

ISO, 2021b. ISO 14044:2021. Environmental Management - Life Cycle Assessment: Requirements And Guidelines. International Organization for Standardization, Geneva.

Jaafar, I.H., Venkatachalam, A., Joshi, K., Ungureanu, A.C., De Silva, N., Rouch, K.E., Dillon, Jr, O.W., Jawahir, Jr, I.S., 2007. Product design for sustainability: a new assessment methodology and case studies. In: Kutz, M. (Ed.), Environmentally Conscious Mechanical Design. https://doi.org/10.1002/9780470168202.ch2.

Kerdlap, P., Cornago, S., 2021. Life cycle costing: methodology and applications in a circular economy. In: Liu, L., Ramakrishna, S. (Eds.), An Introduction to Circular Economy. Springer Nature Singapore, pp. 499–525. https://doi.org/10.1007/978-981-15-8510-4.

Klöpffer, W., Renner, I., 2008. Life-cycle based sustainability assessment of products. In: Schaltegger, S., et al. (Ed.), Environmental Management Accounting for Cleaner Production. Springer Science + Business Media B.V., pp. 91–102.

Kobayashi, T., Suzuki, E., Takao, S., Doi, H., 2012. Long working hours and metabolic syndrome among Japanese men: a cross-sectional study. BMC Public Health 12 (1), 395. https://doi.org/10.1186/1471-2458-12-395.

Liu, L., Ramakrishna, S., 2021. An Introduction to Circular Economy. Springer Nature Singapore Pte Ltd.

Liu, F., Liu, H., Yang, N., Wang, L., 2021. Comparative study of municipal solid waste incinerator fly ash reutilization in China: environmental and economic performances. Resour. Conserv. Recycl. 169, 105541. https://doi.org/10.1016/j.resconrec.2021.105541.

Machin Ferrero, L.M., Wheeler, J., Mele, F.D., 2022. Life cycle assessment of the argentine lemon and its derivatives in a circular economy context. Sustain. Prod. Consum. 29, 672–684. https://doi.org/10.1016/j.spc.2021.11.014.

Malabi Eberhardt, L.C., van Stijn, A., Nygaard Rasmussen, F., Birkved, M., Birgisdottir, H., 2020. Development of a life cycle assessment allocation approach for circular economy in the built environment. Sustainability 12 (22), 9579. https://doi.org/10.3390/su12229579.

Maranesi, C., De Giovanni, P., 2020. Modern circular economy: corporate strategy, supply chain, and industrial symbiosis. Sustainability 12, 9383. https://doi.org/10.3390/su12229383.

Martinez-Sanchez, V., Tonini, D., Møller, F., Astrup, T.F., 2016. Life-cycle costing of food waste management in Denmark: importance of indirect effects. Environ. Sci. Technol. 50, 4513–4523. https://doi.org/10.1021/acs.est.5b03536.

Mayanti, B., Helo, P., 2022. Closed-loop supply chain potential of agricultural plastic waste: economic and environmental assessment of bale wrap waste recycling in Finland. Int. J. Prod. Econ. 244, 108347. https://doi.org/10.1016/j.ijpe.2021.108347.

Merli, R., Preziosi, M., Acampora, A., 2018. How do scholars approach the circular economy? A systematic literature review. J. Clean. Prod. 178, 703–722. https://doi.org/10.1016/j.jclepro.2017.12.112.

Miah, J.H., Koh, S.C.L., Stone, D., 2017. A hybridised framework combining integrated methods for environmental Life Cycle Assessment and Life Cycle Costing. J. Clean. Prod. 168, 846–866.

Michalopoulos, G., Kasapi, K.A., Koubouris, G., Psarras, G., Arampatzis, G., Hatzigiannakis, E., Kavvadias, V., Xiloyannis, C., Montanaro, G., Malliaraki, S., Angelaki, A., Manolaraki, C., Giakoumaki, G., Reppas, S., Kourgialas, N., Kokkinos, G., 2020. Adaptation of Mediterranean olive groves to climate change through sustainable cultivation practices. Climate 8, 54. https://doi.org/10.3390/cli8040054.

Mies, A., Gold, S., 2021. Mapping the social dimension of the circular economy. J. Clean. Prod. 321, 128960. https://doi.org/10.1016/j.jclepro.2021.128960.

Min, Y.I., Anugu, P., Butler, K.R., Hartley, T.A., Mwasongwe, S., Norwood, A.F., Sims, M., Wang, W., Winters, K.P., Correa, A., 2017. Cardiovascular disease burden and socioeconomic correlates: findings from the Jackson heart study. J. Am. Heart Assoc. 6 (8). https://doi.org/10.1161/JAHA.116.004416.

Moreau, V., Sahakian, M., van Griethuysen, P., Vuille, F., 2017. Coming full circle: why social and institutional dimensions matter for the circular economy. J. Ind. Ecol. 21, 497–506. https://doi.org/10.1111/jiec.12598.

Niero, M., Hauschild, M.Z., 2017. Closing the loop for packaging: finding a framework to operationalize circular economy strategies. Procedia CIRP 61, 685–690. https://doi.org/10.1016/j.procir.2016.11.209.

Niero, M., Olsen, S.I., 2016. Circular economy: to be or not to be in a closed product loop? A life cycle assessment of aluminium cans with inclusion of alloying elements. Resour. Conserv. Recycl. 114, 18–31. https://doi.org/10.1016/j.resconrec.2016.06.023.

Nikkhah, A., Firouzi, S., Dadaei, K., Van Haute, S., 2021. Measuring circularity in food supply chain using life cycle assessment;refining oil from olive kernel. Foods 10, 590. https://doi.org/10.3390/foods10030590.

Padilla-Rivera, A., Russo-Garrido, S., Merveille, N., 2020. Addressing the social aspects of a circular economy: a systematic literature review. Sustainability 12 (19), 7912. https://doi.org/10.3390/su12197912.

Pampuri, A., Casson, A., Alamprese, C., Di Mattia, C.D., Piscopo, A., Difonzo, G., Conte, P., Paciulli, M., Tugnolo, A., Beghi, R., Casiraghi, E., Guidetti, R., Giovenzana, V., 2021. Environmental impact of food preparations enriched with phenolic extracts from olive oil mill waste. Foods 10, 980. https://doi.org/10.3390/foods10050980.

Peña, C., Civit, B., Gallego-Schmid, A., Druckman, A., Caldeira-Pires, A., Weidema, B., Mieras, E., Wang, F., Fava, J., Canals, L.M., Cordella, M., Arbuckle, P., Valdivia, S., Fallaha, S., Motta, W., 2021. Using life cycle assessment to achieve a circular economy. Int. J. Life Cycle Assess. 26 (2), 215–220. https://doi.org/10.1007/s11367-020-01856-z.

Perone, G., 2019. Crescita economica e riduzione Dei GHGS: un problema globale. Ital.Rev.Agric.Econ. 74 (1), 19–31. https://doi.org/10.13128/REA-25477.

Poponi, S., Arcese, G., Pacchera, F., Martucci, O., 2022. Evaluating the Transition to the Circular Economy in the Agri-Food Sector: Selection of Indicators. Resour. Conserv. Recycl. 176, 105916.

Reinales, D., Zambrana-Vasquez, D., Saez-De-Guinoa, A., 2020. Social life cycle assessment of product value chains under a circular economy approach: a case study in the plastic packaging sector. Sustainability 12, 6671. https://doi.org/10.3390/su12166671.

Rigamonti, L., Mancini, E., 2021. Life cycle assessment and circularity indicators. Int. J. Life Cycle Assess. 26 (10), 1937–1942. https://doi.org/10.1007/s11367-021-01966-2.

Rödger, J.M., Kjær, L.L., Pagoropoulos, A., 2018. Life cycle costing: an introduction. In: Hauschild, M.Z., Rosenbaum, R.K., Olsen, S.I. (Eds.), Life Cycle Assessment: Theory And Practice. Springer, pp. 373–400. https://doi.org/10.1007/978-3-319-56475-3.

Rodrigues, M.A., Coelho, V., Arrobas, M., Gouveia, E., Raimundo, S., Correia, C.M., Bento, A., 2019. The effect of nitrogen fertilization on the incidence of olive fruit fly, olive leaf spot and olive anthracnose in two olive cultivars grown in rainfed conditions. Sci. Hortic. 256, 108658. https://doi.org/10.1016/j.scienta.2019.108658.

Rodriguez-Anton, J.M., Rubio-Andrada, L., Celemín-Pedroche, M.S., Alonso-Almeida, M.D.M., 2019. Analysis of the relations between circular economy and sustainable development goals. J. Sustain. Dev. World Ecol.Int. https://doi.org/10.1080/13504509.2019.1666754.

Roos Lindgreen, E., Mondello, G., Salomone, R., Lanuzza, F., Saija, G., 2021. Exploring the effectiveness of grey literature indicators and life cycle assessment in assessing circular economy at the micro level: a comparative analysis. Int. J. Life Cycle Assess. 26 (11), 2171–2191. https://doi.org/10.1007/s11367-021-01972-4.

Rufí-Salís, M., Petit-Boix, A., Villalba, G., Gabarrell, X., Leipold, S., 2021. Combining LCA and circularity assessments in complex production systems: the case of urban agriculture. Resour. Conserv. Recycl. 166, 105359. https://doi.org/10.1016/j.resconrec.2020.105359.

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., 2017. How to assess product performance in the circular economy? Proposed requirements for the design of a circularity measurement framework. Recycling 2, 6. https://doi.org/10.3390/recycling2010006.

Sala, S., Reale, F., Cristobal-Garcia, J., Marelli, L., Pant, R., 2016. Life Cycle Assessment for the Impact Assessment of Policies. EUR 28380 EN. Publications Office of the European Union, Luxembourg. https://doi.org/10.2788/318544.

Salameh, P., Waked, M., Baldi, I., Brochard, P., Saleh, B.A., 2006. Respiratory diseases and pesticide exposure: a case-control study in Lebanon. J. Epidemiol. Community Health 60 (3), 256–261. https://doi.org/10.1136/jech.2005.039677.

Saunders, M.N.K., Bristow, A., Thornhill, A., Lewis, P., 2019. Understanding research philosophy and approaches to theory development. In: Saunders, M.N.K., Lewis, P., Thornhill, A. (Eds.), Research Methods for Business Students. 8th edition, Pearson Education, Harlow, pp. 128–171.

Schroeder, P., Anggraeni, K., Weber, U., 2019. The relevance of circular economy practices to the sustainable development goals. J. Ind. Ecol. 23, 77–95. https://doi.org/10.1111/jiec.12732.

Shemfe, M.B., Gadkari, S., Sadhukhan, J., 2018. Social hotspot analysis and trade policy implications of the use of bioelectrochemical systems for resource recovery from wastewater. Sustainability 10. https://doi.org/10.3390/su10093193.

Silvestri, L., Forcina, A., Di Bona, G., Silvestri, C., 2021. Circular economy strategy of reusing olive mill wastewater in the ceramic industry: how the plant location can benefit environmental and economic performance. J. Clean. Prod. 326, 129388. https://doi.org/10.1016/j.jclepro.2021.129388.

van Stijn, A., Malabi Eberhardt, L.C., Wouterszoon Jansen, B., Meijer, A., 2021. A Circular Economy Life Cycle Assessment (CE-LCA) model for building components. Resour. Conserv. Recycl. 174, 105683. https://doi.org/10.1016/j.resconrec.2021.105683.

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 (5), 2472. https://doi.org/10.3390/su13052472.

Strano, A., Stillitano, T., Falcone, G., Gulisano, G., 2013. In: L'approccio Life Cycle Costing (LCC) come strumento di supporto alle decisioni: la valutazione economico-finanziaria di un impianto di produzione del miele in Calabria. Rivista di Economia Agraria (REA), 2, pp. 63–90. ISSN 0035-6190.

Suhariyanto, T.T., Wahab, D.A., Rahman, M.N.A., 2017. Multi-life cycle assessment for sustainable products: a systematic review. J. Clean. Prod. 165, 677–696. https://doi.org/10.1016/j.jclepro.2017.07.123.

Swarr, T.E., Hunkeler, D., Klöpffer, W., Pesonen, H.-L., Ciroth, A., Brent, A.C., Pagan, R., 2011. Environmental life cycle costing: a code of practice. Int. J. Life Cycle Assess. 16, 389–391. https://doi.org/10.1007/s11367-011-0287-5.

Szumilas, M., 2010. Explaining odds ratios. J. Can. Acad. Child Adolesc. Psychiatry 19, 227–229. https://doi.org/10.1136/bmj.c4414.

Uceda-Rodríguez, M., López-García, A.B., Moreno-Maroto, J.M., Cobo-Ceacero, C.J., Cotes-Palomino, M.T., Martínez García, C., 2021. Evaluation of the environmental benefits associated with the addition of olive pomace in the manufacture of lightweight aggregates. Materials 13, 2351. https://doi.org/10.3390/ma13102351.

UNEP, 2020. In: Benoît Norris, C., Traverso, M., Neugebauer, S., Ekener, E., Schaubroeck, T., Russo Garrido, S., Berger, M., Valdivia, S., Lehmann, A., Finkbeiner, M., Arcese, G. (Eds.), Guidelines for Social Life Cycle Assessment of Products And Organizations 2020. United Nations Environment Programme (UNEP).

UNEP, 2021. In: Traverso, M., Valdivia, S., Luthin, A., Roche, L., Arcese, G., Neugebauer, S., Petti, L., D'Eusanio, M., Tragnone, B.M., Mankaa, R., Hanafi, J., Benoît Norris, C., Zamagni, A. (Eds.), Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA) 2021. United Nations Environment Programme (UNEP).

Valdivia, S., Backes, J.G., Traverso, M., Sonnemann, G., Cucurachi, S., Guinée, J.B., Schaubroeck, T., Finkbeiner, M., Leroy-Parmentier, N., Ugaya, C., Peña, C., Zamagni, A., Inaba, A., Amaral, M., Berger, M., Dvarioniene, J., Vakhitova, T., Benoit-Norris, C., Prox, M., Foolmaun, R., Goedkoop, M., 2021. Principles for the application of life cycle sustainability assessment. Int. J. Life Cycle Assess. 26, 1900–1905. https://doi.org/10.1007/s11367-021-01958-2.

Vlyssides, A.G., Lamprou, G.K., Vlysidis, A., 2017. Industrial case studies on the detoxificaton of OMWW using Fenton oxidation process followed by biological processes for energy and compost production. In: Galanakis, C.M. (Ed.), Olive Mill Waste: Recent Advances for Sustainable Management. 1st edition, Academic Press, London, UK, pp. 119–138.

Walker, A.M., Opferkuch, K., Roos Lindgreen, E., Simboli, A., Vermeulen, W.J.V., Raggi, A., 2021. Assessing the social sustainability of circular economy practices: industry perspectives from Italy and the Netherlands. Sustain. Prod. Consum. 27, 831–844. https://doi.org/10.1016/j.spc.2021.01.030.

Social Circular Economy (2017). Social Circular Economy – opportunities for people, planet and profit. Report, retrieved from: https://circulareconomy.europa.eu/platform/en/knowledge/social-circular-economy-opportunities-people-planet-and-profit