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ATTI

X Convegno dell'Associazione Rete Italiana LCA
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INNOVAZIONE E CIRCOLARITÀ

Il contributo del *Life Cycle Thinking* nel Green Deal per la neutralità climatica

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A proposal of customized Life Cycle model to circularity challenges in the olive-oil supply chain

Teodora Stillitano[1*], Emanuele Spada[1], Nathalie Iofrida[1],
Giacomo Falcone[1], Agata Nicolosi[1], Giovanni Gulisano[1], Anna Irene De Luca[1]

Abstract: The attention to a sustainable production, obtained according to the principles of circular economy, concerns various production sectors, including agriculture. Specifically, the adoption of circular strategies for those sectors from which high quantities of by-products emerge could prove to be a winning strategy in terms of reducing environmental impacts while increasing profitability. This study analyses the possibility of switching from a linear take-make-dispose system to a circular cradle to cradle system for the olive oil sector. The proposal concerns a customized Life Cycle model within the PRIN, 2017 project entitled "DRiving the itAlian agri-food SysTem into a Circular economy model" (DRASTIC). This model will implement Life Cycle approaches applied to the agro-ecological and agro-industrial subsystems to examine environmental, economic and social performances of circular economy solutions.

1. Introduction

The search for long-term solutions to recreate a balanced coexistence between ecological and economic systems is at the attention of all developed and developing countries. Circular economy (CE) could provide the key paradigm in the coming decades to rethink the way we behave as consumers and producers. The concept of CE is particularly linked to sustainable development with timely, relevant and practical objectives (Kristensen and Mosgaard 2020; Saidani, 2017). According to Ellen MacArthur Foundation (2015), the industrial economy during its evolution and diversification has never gone beyond the fundamental characteristic established in the early days of industrialization: the linear model of consumption of resources that follows a "take-make-dispose" model. Companies extract materials, apply energy and labour to manufacture a product and sell it to a final consumer, who then discards it when it no longer serves its purpose. While great strides have been made in improving resource efficiency, any system based on consumption rather than restorative use of resources entails significant losses along the entire value chain. The linear economy model has failed to address the imbalances that are currently being created between the limited supply and demand of natural resources. For these reasons, the search for an industrial model capable of increasing sales revenues by reducing material inputs has increased interest in concepts related to the circular economy. The circular economy is based on the principle of "reducing, reusing and recycling", transforming the traditional open linear model of "resources/products/waste" into a cyclical model of "resources /products/waste/resources" (Ghisellini et al. 2016; Xue et al. 2019). Today the circular economy has entered a new phase

[1] Department of Agriculture (AGRARIA), University "Mediterranea" of Reggio Calabria, Italy
* Email: teodora.stillitano@unirc.it

of development, with growing applications (Stahel, 2010) also in the agri-food sector. According to Del Borghi (2020), agriculture is the main consumer of fresh water resources in the world and over a quarter of the energy used globally is spent on the production and supply of food. The application of CE concepts, in which conservative practices are implemented between the agro-ecological (primary production) and agro-industrial (commercial food production) subsystems, can mitigate the impact of current industrial agriculture.

With a total area of around 9 million ha, the Mediterranean basin provides about 95% of the worldwide olive production (FAOSTAT, 2019); therefore, the olive oil sector constitutes a significant source of income but it is also one of the principal user of resources and producer of olive cultivation by-products (e.g., wood, leaves) and olive processing by-products (e.g., olive pomace, olive mill wastewater). Only in European producing countries, there are about 9.6 million tons/year of by-products from the oil mills and 11.8 million tons of additional biomass from the olive pruning process (Berbel and Posadillo, 2018). These by-products, if not properly disposed of, have a high environmental impact and a high cost. The by-products of the oil industry have a high polluting load and threaten the fertility of the soil and the potability of the aquifers. But also their disposal is economically inconvenient. Instead, careful management can turn into a benefit for the company in economic terms and environmental impact by being part of the circular economy processes. With specific technologies, in fact, 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). In this context, the research project of relevant national interest - PRIN, 2017, entitled "*DRiving the itAlian agri-food SysTem into a Circular economy model"* (DRASTIC), funded by the Italian Ministry of Education, University, and Research (MIUR), was born with the objective of conceptualize the circular paradigm in the agri-food sector, with a focus on the edible olive oils, suggesting and comparing circular solutions. The agro-ecological (olive growing and harvesting), agro-industrial (olive oil production) and consumption subsystems of this supply chain will be considered to address the main challenges for the transition of food supply chains towards the circular economy model. This study illustrates the activities of a specific work package (WP4), within the PRIN project, aimed to define a customized model Life Cycle-based to verify the environmental, economic, and social sustainability of closed-loop strategies in olive-oil sector.

2. Materials and Methods

2.1. WP4 "Impact assessment" within the DRASTIC Project framework

Starting from the study of current linear system, DRASTIC project aims at identifying drivers and constraints for the transition to a circular counterpart. The transition approach used in this project considers extant supply chains as the arena on which building CE pathways, by addressing the most critical challenges (technological, market, coordination, regulatory). The project has two main objectives: I, studying how to foster and manage the transition of agri-food chains into a CE model; and II, evaluating the impacts of different agri-food transition pathways to CE (Cembalo et al. 2020). The project will use a case study approach based on the analysis of the subsystems of olive oil edible chain. Besides being widespread in southern Italy where the research will be undertaken (Campania, Apulia, Calabria and Sicily), the olive oil industry causes important environmental impacts while offering opportunities for by-products valorisation at national level.

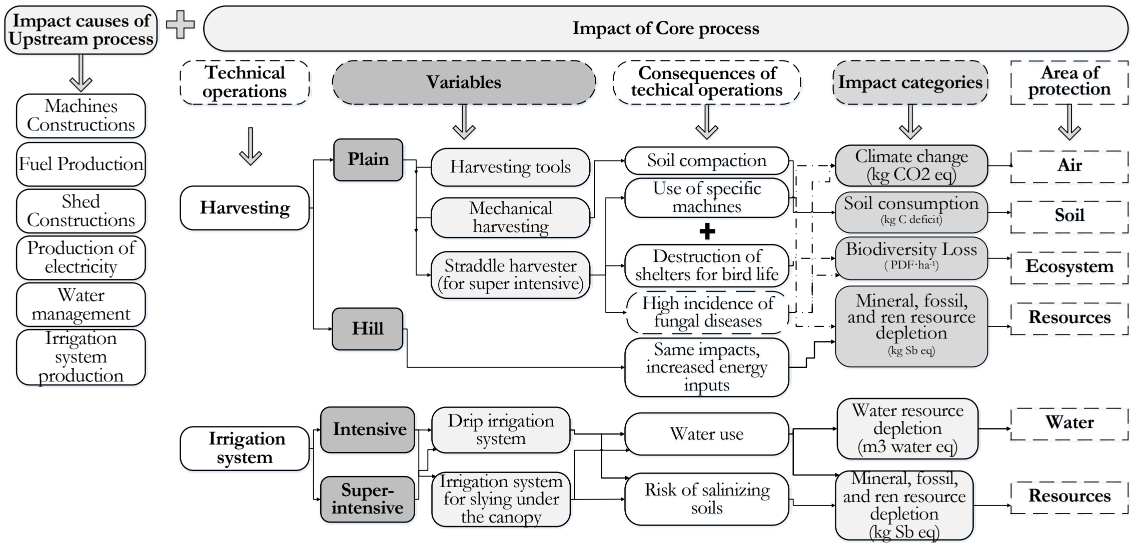
Each subsystem will represent a work package (WP) of the project in which alternative CE pathways will be analysed against the challenges for the transition, i.e., WP1 (Agro-ecological subsystem: olive cultivation and harvesting); WP2 (Agro-industrial subsystem: edible oil production); WP3 (Consumption subsystem) and WP4 (Impact assessment). DRASTIC project is innovative because it specifically addresses some of barriers to the potential circular agri-food chains, while suggesting and comparing possible solutions for the transition. The project is expected to provide insights on business models and coordination strategies, by generating guidelines on suitable technological, market, organizational and regulative solutions, and producing date on impacts that are crucial to orient any future CE pathway.

Exploring the potential contribution of circular approaches to sustainable production in agri-food systems also means understanding how to pay more attention to the social, economic, and environmental aspects of sustainability. However, undertaking such different dimensions is methodologically challenging and calls into question the epistemological foundations of sustainability science and circular economy. One of the greatest concerns is around the combination of different assessment methods and merging their results in a suitable and believable way (Stillitano et al. 2021). To satisfy these purposes, the Life Cycle (LC) approaches are required to be systemic, multidisciplinary, and multicriterial. Based on these assumptions, WP4 "Impact assessment" aims at providing a customized Life Cycle model, which will implement LC approaches at the agro-ecological and agro-industrial subsystems of olive oil edible chain to examine environmental, economic and social performances of circular economy solutions. LC methodologies, i.e., the Life Cycle Assessment (LCA), Conventional Life Cycle Costing (cLCC), Environmental Life Cycle Costing (eLCC), and the Social Life Cycle Assessment (sLCA), are obtaining a growing consensus in the appraisal of the environmental, economic and social impacts of different agricultural systems (De Luca et al. 2015; Iofrida et al. 2016). In this context, the use of a LC framework, able to capture all sustainability dimensions, can be adapted to evaluate circular economy strategies in an operational and comprehensive way.

2.2. Life Cycle model setting to olive-oil edible chain for assessing the sustainability of circular pathways

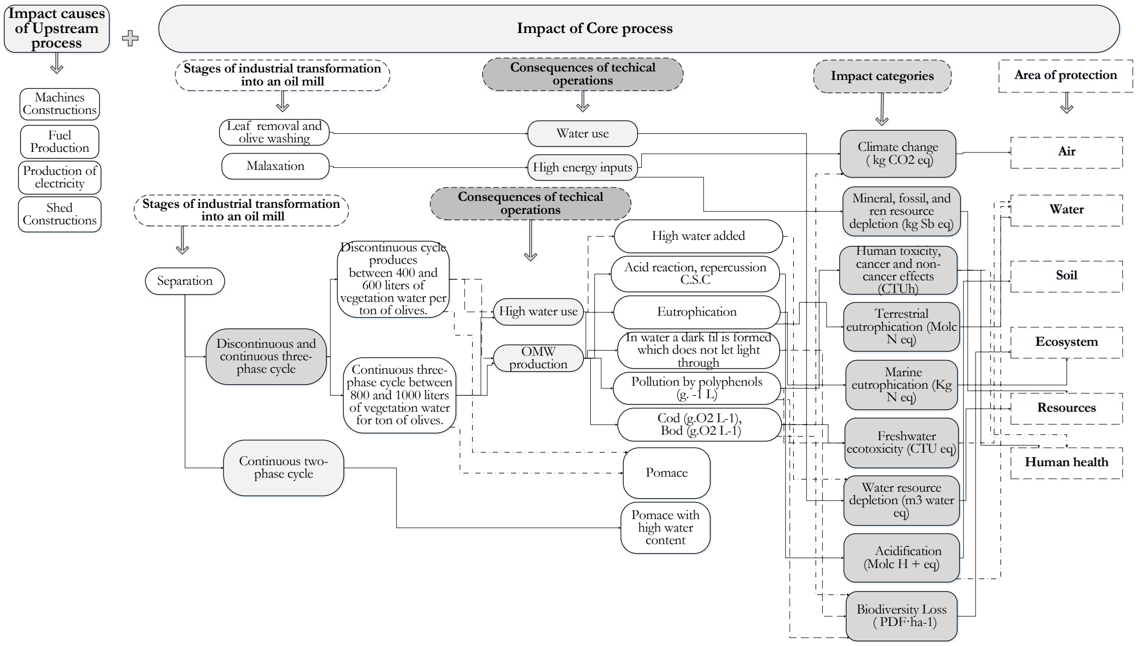
The agro-industrial processes oriented to the production of olives and the extraction of olive oils are responsible for generating many by-products whose management is often problematic. As with other agricultural crops, several environmental issues emerge from the olive cultivation phase, which generate measurable impacts through the LCA methodology. Considering a *cradle-to-cradle* system boundary, for all technical operations in addition to the impacts related to the core process, those related to the upstream process must be considered. About the core process, among the main environmental and ecological issues, facing agricultural operators, are related to soil management with mechanical processes and chemical control of weeds, which generate mainly compaction, oxidation of organic substance, destruction of wildlife shelters, pollution of surface and groundwater, especially in hill erosion phenomena. Nutrition management, if not properly performed, leads to nitrate pollution and eutrophication of water, 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. By way of example, the olive harvest operation, as shown in Figure 1, if mechanically carried out, can lead to phenomena of soil compaction and destruction of shelters for wildlife, high spread of fungal diseases. Also considering the exclusive use of the machines for this technical operation, it requires a large initial investment and especially in the hills require high energy inputs. 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. Both of these operations are therefore linked to specific potential impact categories (according to LCA methodology) and, then, to areas of protection to be considered.

Figure 1: Example of environmental concerns and impact categories of some agricultural operations in the olive oil chain.



The extraction phase of olive oil generates by-products that can have a great impact on the land and water environment, due to their high phytotoxicity (Figure 2). The quantity and physico-chemical characteristics of the by-products produced depend mainly on the technological method used for extraction: traditional and three-stage production processes with highest wastewater content; two-stage production process with no vegetation water, but pomace with high moisture content. Mill wastewater has a high organic load and numerous contaminants (phenolic compounds), these are phytotoxic and poorly biodegradable (Vlyssides et al. 2017). The pomace of three-phase plants has 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.

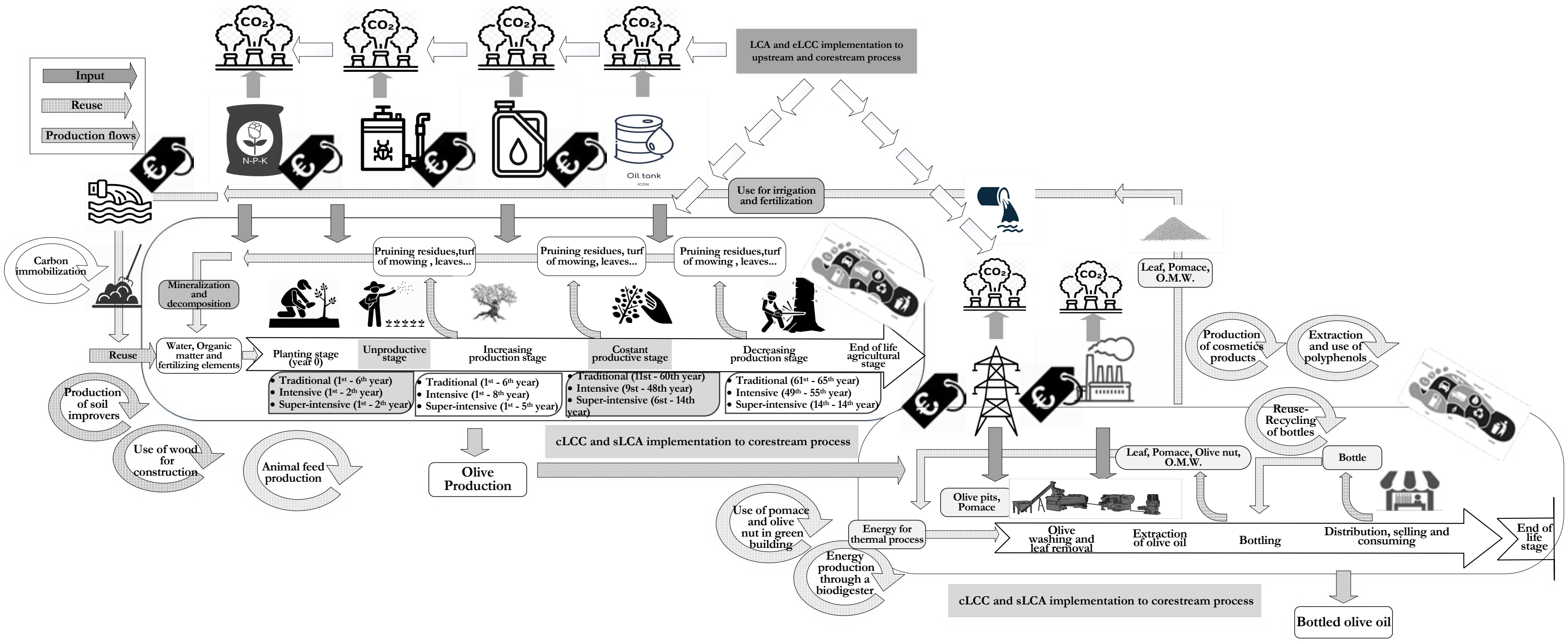
Figure 2: Example of environmental concerns and impact categories of the industrial phase in the olive oil chain.



Several concerns can affect the socio-economic performance of 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 low level of mechanization. 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).

Figure 3 shows a stylized flow-chart of the olive oil chain by highlighting all the different stages of agricultural production, industrial processing (extraction of oil and bottling), and distribution, selling and consuming. In this figure it is possible to distinguish the input of raw materials entering in the whole process; the flows related to the normal flow of olives obtained in the agricultural stage at the oil extraction stage; the reuse about the re-introduction of by-products into the agricultural or processing production process. As far as the agricultural phase is concerned, the different olive cultivation systems that are now widespread in Italy are considered: Traditional, Intensive, and Super-intensive.

Figure 3: Design of Life Cycle-based model to assess circularity pathways in olive-oil chain.



Although the production phases are identical, i.e., "planting phase", "unproductive phase", "constant production phase", "decreasing production phase" and "end of life phase", they differ in the amount of input and output and in their temporal horizon according to the system adopted. The main by-products of the agricultural phase are the residual branches of pruning and the turf of mowing or green manure. In a context of linear economy pruning residues were burned in the field, with high environmental impacts due to the production of CO_2. Their reintroduction during the agricultural phase by shredding the residuals of pruning and the turf can represent an efficient circular economy approach. These represent a good source of organic substance that through natural mineralization can replace a part of chemical fertilizers. In the industrial processing phase, the following by-products can emerge: leaves obtained from the cleaning of olives, vegetation water obtained from the washing of olives and the separation phase, pomace (with high water content in two-phase mill) and olive pits. As already mentioned, olive pomace and vegetation water can have a high environmental impact. A circular economy approach 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 pits as fuel to obtain the thermal energy needed for the processing plant (Benalia et al. 2021). Moreover, considering the bottling phase, the possibility of recycling empty bottles of olive oil would allow a great saving in environmental terms. Once the main circular strategies, adopted in the Italian olive oil supply chain, will be identify by the previous WP1 and WP2 of the PRIN project, Life Cycle approaches (LCA, LCC and social LCA) will be implemented to verify their level of sustainability, as well as their degree of effectiveness in overcoming the limits present in the current scenarios of open-loop production.

3. Conclusions

This work illustrates the research activities, within the DRASTIC project, aimed to set a Life Cycle model to olive-oil supply chain for assessing the environmental, economic, and social sustainability of circular strategies in olive-oil sector. The model will implement and apply Life Cycle approaches, i.e. LCA, LCC, sLCA, to the agro-ecological (olive growing and harvesting) and agro-industrial (olive oil production) subsystems, which cause significant environmental impacts by generating many by-products whose management is often problematic. In the scientific literature, the integrated applications of LC approaches and circular economy strategies refer to single process components (e.g., agricultural phase, mill wastewater, and pomace) rather than to the overall production process. Therefore, the LC model will allow us to comprehensively assess the environmental, economic and social performance of circular strategies along the entire olive-oil supply chain. Closed-loop strategies within the sector can make it possible to reuse by-products as a possible resource capable to move the system toward a model more sustainable and economically efficient. 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 with the aim of reducing environmental impacts and increase profitability.

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