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Transitioning towards a circular economy agri-food model: strategies to move from goals to objectives in the olive oil sector

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ABSTRACT

Addressing the overuse of natural resources is crucial, and the circular economy (CE) offers a solution by turning waste into value to meet societal needs. CE may support business development without increasing resource exploitation. However, transitioning to CE models presents socio-technical challenges across the value chain, and the adoption of circular practices into established systems requires to overcome several system lock-ins. This study focuses on the agri-food sector, particularly the olive oil supply chain, chosen for its economic significance and potential for upcycling by-products. Through semi-structured interviews with 17 key informants, using the multi-level perspective (MLP) framework as conceptual background, this study explores how niche-level innovations can challenge and reconfigure existing regimes, leading to systemic change. The findings suggest potential CE transition pathways and highlight the complex socio-technical interactions necessary for sustainable transformation.

1. Introduction

As finding an answer to the overuse of natural resources can no longer be postponed (IPCC, 2019; Steffen et al., 2015; Aschemann-Witzel and Stangherlin, 2021), the circular economy (CE) narrative suggests turning waste into value as a new way of satisfying societal needs. The CE goal is moving from resource-based to eco-effective growth through the generation of upcycling processes and cyclical cradle-to-cradle metabolisms that allow materials to preserve their resource status over time (EMF, 2013; Borrello et al., 2017). Besides making economic sense, this would enable business development without increasing the exploitation of natural resources (Eiroa et al., 2019; Cembalo et al., 2020). However, the shift of an industrial sector into circular economy models is a socio-technical transition that involves all actors of the value chain (EMF SUN, 2015; Borrello et al., 2020). Each loop of a CE system can entail tackling major barriers, such as political, legal, economic, social, and technological barriers (Kirchherr et al., 2018). Furthermore, integrating circular technologies and practices into well-established production systems requires profound managerial changes and business model innovation (Boons and Lüdeke-Freund, 2013; De Jesus and Mendonça, 2018). Briefly put, CE entails a drastic technological and social change at multiple levels and among all stakeholders.

The current research addresses the issues of CE transition focusing on the agri-food sector, which is largely affected by environmental impacts of production, resource depletion, and food losses and waste along the supply chain (Borrello et al., 2016; Ghisellini et al., 2016; Esposito et al., 2020). Even though organic farming and corporate social responsibility programmes have made this sector more sustainable over time (Muller et al., 2017; Stranieri et al., 2019), long term strategies to decouple its growth from resource depletion are far to be defined. A circular agri-food system would involve restorative agroecological practices (Lord and Sakrabani, 2019), as well as biomass valorization in integrated, multi-output production chains (such as biorefineries) (Liu et al., 2021), where cascading processes following the biomass value pyramid are prioritized (Stegmann et al., 2020).

This study contributes to literature on CE transitions by analysing future perspectives of circular economy in a specific agri-food supply

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chain, that is the one of olive oil in Sicily, Southern Italy. This supply chain was chosen for the relevant economic value of olive oil in Mediterranean countries (Raimondo et al., 2021), for the economic and ecological issues related to the management of its residues and by-products, as well as for their upcycling potential. To illustrate, the olive oil supply chain generates olive tree pruning biomass, olive leaves, olive kernels, olive pomace, and olive mill wastewater, whose management is significant economic burden for producers (Tamasi et al., 2019). Recently, the valorization of these biomasses has been partly achieved through biogas plants, as alternative CE strategies able to turn these materials from problem to economic opportunity and as important solution to the incorrect disposal of olive processing residues. However, there are still illegal dumping practices in agricultural fields, rivers, lakes and seas (Gullon et al., 2020), which can lead to harmful environmental impacts, such as phytotoxicity and eutrophication (Goldsmith et al., 2018; Nunes et al., 2016).

So far, different aspects of the transition of the olive oil sector to circular economy have been addressed. For instance, some studies have explored the role of individual firms and technologies in enabling circular practices, such as through case studies of vertically integrated companies managing olive pomace (Stempfle et al., 2022). Others have analysed circular business models based on the valorization of olive waste streams, especially in the Mediterranean context, using a business model canvas approach (Donner and Radić, 2021). Additional research has focused on traditional table olive groves, mapping a wide range of circular practices, and identifying key drivers and barriers at the farm level (Martínez-Moreno et al., 2024). More broadly, literature in this field has investigated waste-to-energy strategies, bio-based product development, institutional enablers and barriers, and stakeholder engagement processes in agri-food transitions (Gazal et al., 2025). Despite these contributions, the socio-technical dynamics underpinning CE transitions in the olive oil sector remain underexplored. Existing studies tend to adopt firm-level or sectoral perspectives, often lacking a systemic analysis of how innovations at the niche level interact with dominant production regimes and broader landscape pressures. As a result, there is limited understanding of how systemic change can emerge from the complex interplay between actors, practices, and institutions across multiple levels.

To identify potential CE transition pathways in the agri-food sector, particularly in the context of the Sicilian olive oil supply chain, a comprehensive and systemic analysis of the socio-technical configuration surrounding it is therefore required. Transition pathways involve a fundamental shift from one dynamic equilibrium to another, which arises from disruptive and systemic changes that occur at multiple levels simultaneously (Markard et al., 2012). This goes beyond simply adopting or adapting technological innovations, requiring a profound transformation in the existing supply chains. We have sought to capture the complexity of this transformation by analysing its key driving elements: the dominant rules, structures, and norms that shape the current system; the innovative ideas or practices that emerge at the fringes of the existing system; and the broader context in which the system operates. Our study draws on literature that analyses transition processes through the Multi-Level Perspective (MLP) framework (Geels, 2002, 2005; Schot and Geels, 2008). The MLP is a well-established theoretical approach for understanding socio-technical transitions. It examines the interactions among three interconnected levels: niche (micro-level), regime (meso-level), and landscape (macro-level). According to the MLP, these interactions can generate potential pathways for long-term change (Geels, 2010, 2019; Smith et al., 2005). Specifically, when innovations at the niche level gain sufficient momentum and support, they can challenge the existing regime. These innovations exert pressure for change on the regime by exploiting windows of opportunity created by shifts at the landscape level. This complex and often hindered process ultimately leads to a reconfiguration of the entire system.

While MLP has been extensively applied to study sectors like energy and transport (e.g., Nilsson and Nykvist, 2016; Magnani and Cittati, 2022), its application to agricultural and agri-food systems has been relatively limited. Furthermore, research on transitions has generally given little attention to agri-food systems. In this context, the aim of our study is to investigate how niche-level circular practices and innovations in the olive oil supply chain may challenge and potentially reconfigure the dominant production regime in Sicily. We seek to understand the enabling and constraining factors that shape this process, and to identify concrete transition pathways that can guide stakeholders and policymakers. This research thus aims to contribute to transition theory in the agri-food domain by operationalizing the MLP framework in an empirical study of circular economy implementation. More specifically, to explore the CE transition in the olive oil supply chain of the Sicilian region, we collected qualitative data by means of semi-structured, open-ended interviews. During the summer of 2022 and autumn 2023, a total of 17 key-informants were interviewed, including farmers, olive processors, advisors, agriculture associations representatives and academics. The interviews transcripts were then analysed to figure out dominant themes and conceptual patterns. The results were framed into the conceptual framework of the multi-level perspective, assumed as theoretical anchor to discuss the transition process at hand. After this, outcomes were critically analysed to suggest potential transition pathways. Through this approach, our study offers a number of original contributions. It introduces a systemic analysis of circular economy transitions in the olive oil sector using the MLP framework, thus extending its application to agri-food systems. It provides empirically grounded insights on the specific context of Sicily, highlighting how regional socio-technical configurations affect the uptake of circular practices. Moreover, it identifies actionable transition pathways and governance strategies, offering value for both researchers and practitioners aiming to support sustainability transitions in traditional agricultural sectors.

The remainder of this paper is organized as follows: Section 2 justifies the need for this research in the specific study area. Section 3 presents an overview of the literature on MLP and the agri-food system. Section 4 outlines the methodological approach, while Section 5 presents and discusses the results. Conclusive considerations are elaborated in Section 6.

2. Study area

Sicily is the third largest Italian region in terms of olive-growing area and olive oil production, after Puglia and Calabria, and is the first region in terms of table olive production. The importance of the olive sector in this territory is considerable, with nearly 200,000 farms and about 700 mills (Istituto Nazionale di Statistica – ISTAT, 2010). From 1982 to 2010, the total number of farms in the region decreased by almost half, with the average farm size growing from 3.96 ha to 6.32 ha and approximately 2.46 % of the total regional agricultural land dedicated to olive tree cultivation. Olive trees are cultivated by nearly two-thirds of all farms in Sicily (around 140,000 commercial growers), excluding non-commercial growers. The olive oil sector in Sicily follows a pyramidal structure in terms of both size and influence. At the base of the pyramid are numerous small-scale olive growers, with 78 % of olive farms in Sicily smaller than 5 ha and 37 % of them smaller than 1 ha. In the middle of the pyramid, there are approximately 700 olive mills, scattered throughout the region, and significantly fewer than the number of olive growers due to the costs of the technology required for olive-to-oil processing. At the top of the pyramid, approximately 250 bottlers dominate, often engaged in international market sales (Istituto Nazionale di Statistica - ISTAT, 2010). Olive oil production in Sicily is characterized by quality and variety, resulting from a multiplicity of microclimates that affect the qualitative performance of olive groves and the genetic variability of Sicily's native olive heritage (Grilo et al., 2020). Although there is a positive evolution of national and international demand for extra-virgin olive oil (Data Bridge Market Research, 2021) and all the requirements that lead to excellent quality production,

Sicilian companies risk not taking advantage of the prospects that the market presents due to a series of structural, organizational and institutional delays, which hinder a balanced development of the supply chain. Moreover, the supply chain is characterized by seasonality and particularly affected by the alternating production that characterizes the *Olea* genus (Jimenez-Lopez et al., 2020).

The GIS platform processing has facilitated the generation of a georeferenced spatial depiction highlighting regions with significant olive cultivation specialization (Fig. 1). This specialization primarily manifests in two key areas: the entire northern coastal region and the southwestern region. As depicted in the figure, the majority of olive cultivation on the island occurs in non-irrigated areas, characterized by specialized cultivation systems for *Olea*.

The extraction process of olive oil generates significant quantities of byproducts (Otero et al., 2021), including pomace, pits, wastewater, and leaves (Khwaldia et al., 2022). If these byproducts are not properly utilized, they risk causing severe environmental impacts (Souilem et al., 2017). Their valorization involves their use and/or transformation to obtain added value (Siracusa and Ruberto, 2019). The olive oil byproducts represent approximately 40–85 % in weight compared to the olives processed for milling, depending on the processing plants layout (Valenti et al., 2020). The pomace contains crushed olive pits, which are the kernels of the crushed drupe.

Even though the national standard allows the agronomic use of all byproducts as soil improvers, it is preferable to avoid this operation due to the stink caused by the high organic content, their low biodegradability, and the environmental impacts due to their phytotoxicity (El Bilali, 2019). In the last twenty years, all byproducts have been increasingly used as feedstock for anaerobic digestion plants (Murano et al., 2021). As for vegetation water, intensive filtration systems have been recently developed to separate the denser fraction of these waters from the clarified fraction for irrigation purposes. It is worth also noting that all olive processing byproducts are valuable sources of bioactive molecules (e.g., pectin, tannins, polyphenols, anthocyanins), that can be recovered and reused for various purposes, following circular economy approaches (Markhali et al., 2020). Consequently, there is a recent interest in innovations aimed to extract these substances to devote as input of new products, such as cosmetics, functional foods, supplements, and other products (Galanakis, 2015; Palmeri et al., 2022).

3. Theoretical background

3.1. Multilevel perspective

A sustainability transition involves a shift from an unsustainable state to a more balanced and sustainable one, addressing global challenges like climate change, resource depletion, and social inequality (Markard et al., 2012). It necessitates fundamental changes in societal operations, aiming to transform entire systems, including industries, technologies, behaviors, and societal norms. The multilevel perspective (MLP) (Geels, 2002) has emerged as a conceptual framework for understanding sustainability transitions in various industries. The MLP recognizes that achieving sustainability requires significant alterations in production and consumption patterns, moving away from unsustainable systems towards more sustainable alternatives. The framework identifies three levels: niche, regime, and landscape. The niche serves as a space for innovation and experimentation, challenging and disrupting the established rules and practices of the dominant regime. The landscape encompasses the broader societal, economic, and political context in which transitions occur, influenced by cultural values, policies, and market conditions.

The MLP framework has been employed to analyze sustainability transitions in diverse industrial sectors. For instance, in the energy sector, researchers have extensively studied the emergence and adoption of niche innovations like renewable energy technologies (e.g., solar and wind power) (dos Santos Carstens and da Cunha, 2019; Gibbs and Jensen, 2022), which challenge the dominance of fossil fuels. They have also explored how landscape factors such as government policies, market dynamics, and societal attitudes shape energy transitions (Geels et al., 2018). Similarly, the transportation sector has been investigated within the MLP framework, examining the transition from conventional internal combustion engine vehicles to electric vehicles (Figenbaum, 2017). Niche innovations in electric vehicle technology, coupled with supportive policies and evolving consumer preferences, have influenced the transportation regime and facilitated a shift towards more sustainable mobility options (Mazur et al., 2015; Nilsson and Nykvist, 2016).

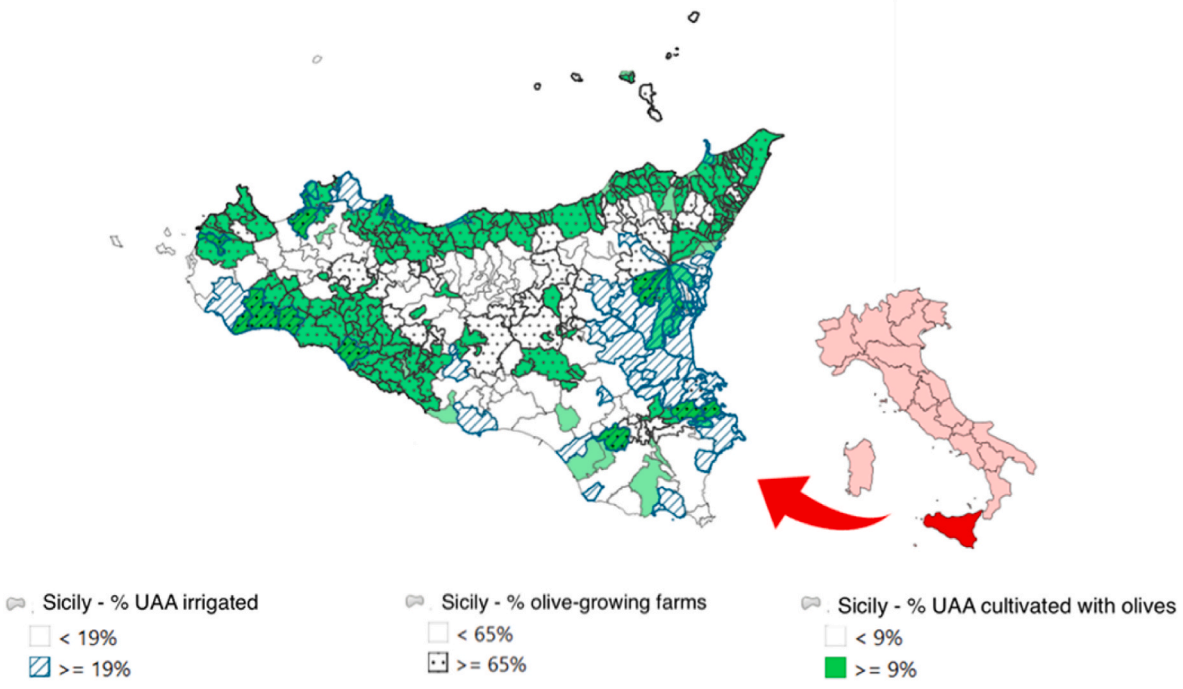

Fig. 1. Study area.

3.2. MLP applications in the agri-food sector

The MLP has emerged also as framework for examining sustainability transitions within the agrifood sector (El Bilali, 2019). While its application in this field is relatively limited compared to other industries, the MLP offers valuable insights into the dynamics of change, as well as the opportunities and barriers present within agricultural and food systems.

One prominent area where the MLP has been applied within the agrifood sector is in the transition toward sustainable agricultural practices. Through the MLP framework, researchers have utilized an understanding of the interactions between niche innovations, dominant regimes, and landscape factors to examine the adoption and diffusion of sustainable farming methods. For instance, studies have investigated how agroecological approaches, like organic farming (Nuijten et al., 2018) and diversified cropping systems (van der Windt and Swart, 2018), challenge the prevailing regime of conventional agriculture. The MLP has shed light on the role of supportive policies (Levidow et al., 2014), innovation networks (Ingram et al., 2015), and firms' dynamic capabilities (Gruchmann et al., 2021) in facilitating the shift toward sustainable farming practices.

Another aspect of the agrifood sector, where the MLP has been employed, is the analysis of alternative food networks (Bui et al., 2016). These networks, encompassing farmers' markets, community-supported agriculture, and local food initiatives (Goodman et al., 2012), often emerge as niche innovations within the food system. Researchers employing the MLP framework have explored the driving forces and obstacles that shape the growth and dissemination of these alternative networks. By comprehending the interplay between niche innovations, the dominant food system regime, and broader landscape factors such as consumer preferences (Zagata, 2012) and policy frameworks (Wiskerke, 2003), valuable insights are obtained regarding the potential of alternative food networks to transform the agrifood sector toward more sustainable and localized food systems.

Moreover, the MLP has been employed to examine circular economy principles within the agrifood sector (Cembalo et al., 2020). Researchers have focused on niche innovations that promote resource efficiency, waste reduction, and the establishment of closed-loop systems within agrifood value chains. For instance, studies have delved into the analysis of organic waste collection and composting projects (Luna and Zambon, 2023). Additionally, the MLP has been used to analyze sustainable packaging initiatives (Miemczyk et al., 2022), such as bio-based or compostable materials, that challenge the prevailing regime of single-use plastics. By comprehending the interplay among niche innovations, dominant regimes, and landscape factors like consumer behavior and policy frameworks (De Rosa et al., 2021), the MLP provides insights into the potential of circular agrifood systems.

4. Methodology

The research consists in the implementation of a qualitative protocol entailing the participation of relevant actors of the supply chain at hand. Deep qualitative information on the present structure and functioning of the Sicilian olive oil sector was collected, through semi-structured, open-ended interviews conducted in two distinct steps within the theoretical framework of MLP (Fig. 2).

Key-informants were selected with the aim to represent the heterogeneous characteristics of the Sicilian territory. In addition, candidates to participate in the study were screened according to their professional profile, eventually including farmers, olive processors, advisors, agriculture associations representatives and academics. Fig. 3 illustrates the participants' profiles, noting that some respondents fulfil multiple roles within the supply chain.

A diverse range of actors was included, varying in farm size, geographical location, and agricultural practices. While the sample was not statistically representative, efforts were made to capture different perspectives within the supply chain, ensuring that insights were drawn from a broad spectrum of experiences.

For consultants and representatives of agricultural associations, priority was given to individuals with direct expertise in the olive oil sector, particularly those with experience in innovation processes, supply chain coordination, and policy advisory roles. Their knowledge provided a deeper understanding of the strategic and operational challenges faced by the sector.

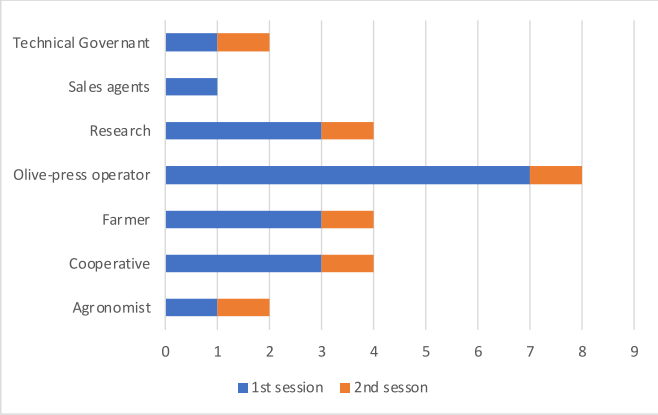

Fig. 3. Expertise areas coverage.

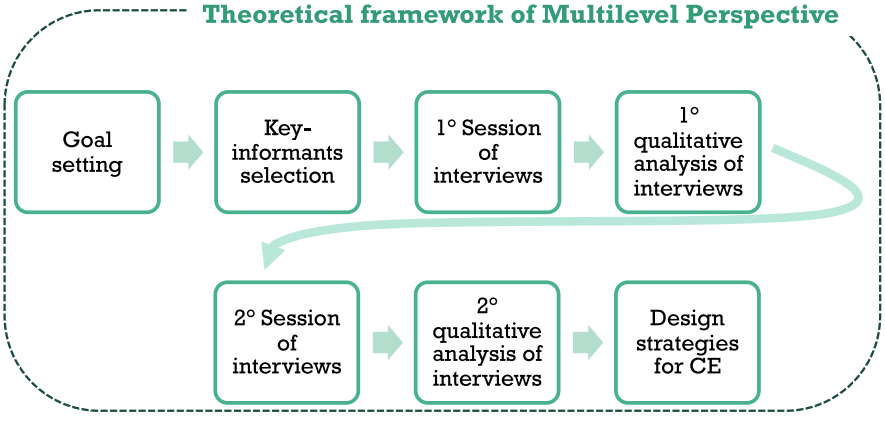

Fig. 2. Flow chart of the research steps.

To mitigate potential bias due to the overrepresentation of certain categories, insights were integrated from actors at different levels of the supply chain, including small and medium-sized enterprises.

A non-directive interview approach was implemented, to facilitate the emergence of non-preordained concepts, and leave space to participants' experiences and sensemaking.

Afterwards, a scoping inductive qualitative analysis of interview transcripts was performed by two researchers, to make an overall sense of the contextual peculiarities of the study area as regards circular economy driving and obstructing factors. This operation was assisted and integrated by a set of brainstorming sessions among a larger group of investigators, with the aim to reduce interpretative bias. The transcripts encompassed numerous intricate, subtle, and conflicting ideas and perspectives. Evaluating and comparing these various interpretations made difficult to determine the dominant ideas or their practical relevance. Therefore, to enhance the validity of the research, the data analysis process involved the utilization of critical thinking, aided by the constant comparative method and deviant case analysis (Silverman, 2005). Adjustments to initial categorizations were made as part of this iterative process. The constant comparative method involved initially analyzing a small portion of the data and establishing preliminary themes and concepts. This analysis process then expanded to include a larger dataset, such as incorporating additional interviews. As for the deviant case analysis, it entailed recognizing the significance of anomalous and divergent perspectives in developing a comprehensive understanding. These alternative opinions were considered important to gain a more holistic view of the subject matter. In the initial phase of the research (1st session of interviews), 14 key informants were interviewed during the summer of 2022, by means of the Zoom video communication platform. The inclusion of further participants ended when the informative saturation point was reached.

About 13 h of video/audio recording were gathered overall, with an average duration of 55 min per interview. Interviews followed a protocol focused on the *status quo* of the Sicilian olive oil supply chain and extant circular practices, to capture information about the current socio-technical transition stage.

Results were framed into the MLP conceptual framework, assumed as theoretical anchor to discuss the transition process under investigation and suggest potential transition pathways.

The initial phase of interviews played a pivotal role in contextualizing the data within the framework of MLP theory and in delineating niches, regimes, and landscape pressures pertinent to the olive supply chain (Fig. 4). However, the emergence of potential strategies for transitioning towards a circular economy appeared in a fragmented manner, posing an interpretive challenge that defied singular paradigmatic classification. Consequently, given the qualitative nature of the analysis and the absence of unequivocal identification of potential design strategies, the researchers proceeded to engage with a second cohort of key informants (2nd session of interviews). Specifically, face-to-face interviews were conducted with three experts from the olive oil sector: a politician, a sector representative and an entrepreneur. No agent sale was involved in this 2nd session as this role he/she was not considered to be fully aware of the internal dynamics between the main actors of the supply chain under investigation. These interviews, totaling 3 h and 20 min, were conducted in autumn 2023 with the explicit consent of the participants. Subsequently, the interviews were transcribed and subjected to content analysis.

The latter group was explicitly prompted to propose potential design strategies aimed at transitioning from linear to circular models.

Information on the example of question considered for the qualitative protocol and 2nd session of interviews is available in the supplementary files (Tables S1 and S2).

5. Results

5.1. Landscape

According to the key informants, there is a confluence of external factors driving the transition towards a circular economy. The ongoing discourse and reports on climate change, concerns about waste disposal, the growth of the global population, and resource scarcity are all interconnected elements that gradually shift consumption habits towards sustainability. These factors also urge entrepreneurs to re-evaluate prevailing production models in favour of more circular approaches. One respondent emphasizes the European Union's directive, stating,

> "We must move toward green agriculture, green farming. So, in addition to the obligations we have by legislation, we have a moral duty to our planet."

European policymakers, as well as national and regional governments, are creating supportive conditions through new regulatory frameworks and incentive systems. Another respondent acknowledges this by stating,

> "The regional Rural Development Plan (RDP) periodically manages to put in place activities that allow us to innovate machinery and plants, both in the primary and processing phases, as well as in the packaging of products."

The European Green Deal promotes the ecological transition as an opportunity for a new development model, with the Circular Economy Action Plan being a significant component. It is complemented by the

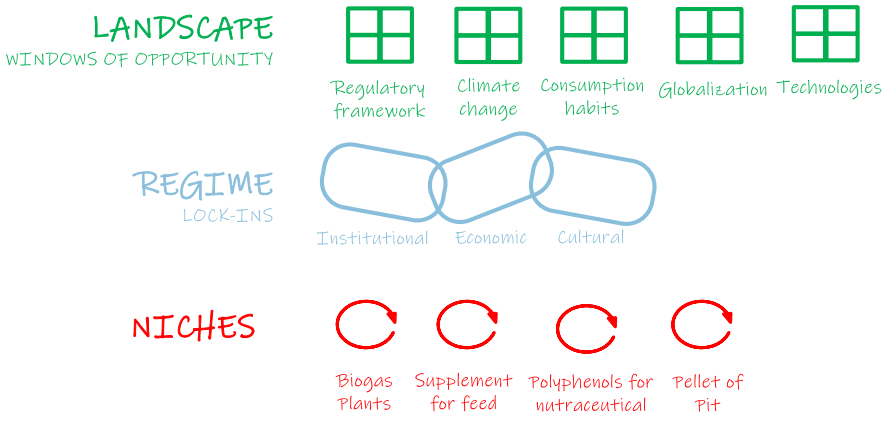

Fig. 4. Graphical scheme of MLP in olive oil industry.

EU's accelerated focus on renewable energy (Reg. EU, 2022/2577), the updated European regulations on biofertilizers, and the provision of funds for modernizing oil mills within the Italian National Recovery and Resilience Plan (PNRR). Simultaneously, there is a discernible emergence of a new type of consumer who is increasingly conscious of the environmental impacts of their choices. They are more attuned to planetary boundaries and exhibit a heightened interest in healthy and functional food, as one interviewee highlights, stating,

> "Global consumers are increasingly interested in environmental, health, and sustainability issues."

Furthermore, we should not underestimate the impetus generated by "negative" factors such as climate change and the abandonment of olive groves in challenging orographic conditions, which accounts for around 30 % of the area in Italy. As one interviewee explains,

> "heat and drought challenge olive growing, which loses significant shares of production … The moment has come for olive farms to rethink their production model in a sustainable way."

Another respondent adds,

> "The quality of Sicilian olive oil is excellent as it is an oil particularly rich in polyphenols. However, olive growing has become economically unsustainable and olive groves are increasingly being abandoned. Supporting the olive supply chain necessarily involves introducing innovations."

Introducing new technologies like precision agriculture and artificial intelligence, capable of enhancing the efficient use of inputs, represents a crucial step in reducing environmental pressure, climate impact, and farmers' costs.

Nevertheless, while landscape pressures are becoming increasingly evident, progress towards a circular transition remains sluggish.

5.2. The regime and its lock-ins

According to the key informants, the socio-technical olive oil regime, which we are studying as a case for investigating transition pathways, is predominantly linear. Operators tend to favour the business-as-usual approach, lacking a well-established corporate environmental culture and adequate infrastructure. The Sicilian olive oil supply chain comprises diverse actors, with the majority being small agricultural businesses that struggle to access the market. They coexist with a few highly competitive companies that serve as exemplars on a national scale. One interviewee asserts,

> "Today, an olive oil producer without a multifunctional business finds it difficult to remain in the market."

The interviews reveal that innovation within the olive oil industry in the past two decades has primarily focused on varietal advancements, cultivation techniques, olive harvesting methods, extraction technology, and bottling processes. However, these incremental innovations have not resulted in the widespread adoption of new business models. In discussions with key informants from the Sicilian olive oil supply chain, it becomes evident that there has been a lack of full integration of olive residues into a circular economy system. Companies are not yet aware of the potential of using all by-products generated throughout various stages of the supply chain. As one interviewee highlights,

> "It's as if there were millions of coins on the ground that no one picks up."

The interviews shed light on the challenges posed by an inadequate administrative and regulatory framework for the transition towards a circular economy. Key institutional barriers that emerged include the absence of a comprehensive vision, governance, shared direction, coordination, and effective information dissemination. As one interviewee pointed out,

> "There is a lack of communication and dissemination of information."

These barriers also encompass a slow and intricate bureaucracy, as well as limited preparedness among public officials. Concerns were expressed regarding bureaucracy hindering progress, with comments such as:

> *"Bureaucracy worries and blocks us," "Our cutting-edge projects become outdated by the time they are approved and funded,"* and "*We encounter constraints from the controlling agency that completely hinder our ideas for sustainable water purification."*

These complaints voiced by the key informants highlight the significant role of hypertrophic bureaucracy as an obstacle to the circular economy model. Simplifying and reducing administrative constraints could help facilitate the growth of eco-innovation activities. Overall, respondents lamented the absence of a holistic vision encompassing all aspects necessary to support the transition to a circular economy.

Economic barriers are recognized as significant impediments to the adoption of circular economy (CE) practices (Grafström and Aasma, 2021). Respondents also highlighted economic challenges associated with market uncertainty and the development of new processes and products within the transition to a circular economy. The high initial investment costs for circular business models were recognized as a significant limitation for implementing change. Some key informants mentioned that

> "Environmental sustainability is not always accompanied by economic sustainability."

Moreover, one respondent emphasized the importance of internalizing the social benefits of positive externalities through subsidies, which could facilitate the transition toward a circular economy. Another interviewee revealed that investing in innovation can lead to image and reputation benefits, but supporting higher fixed and variable costs risks making the final product less competitive in terms of price, which can impact cost-conscious consumers. Consequently, technically and economically larger companies are now contemplating whether a circularity certification could be marketed to achieve greater compensation.

Lastly, the distances covered for the transportation of by-products and associated costs should also be taken into consideration. One interviewee stated,

> "For the management of by-products, we would need to address the issue of distances because transportation is becoming a limiting factor. Sending a truck to the other side of Sicily is not profitable."

Other concerns raised were the expensive disposal of by-products in landfills and the impracticality of biogas plants due to long distances. As one interviewee put it,

> "If we have to transport a by-product over a distance of 1000 km for disposal, there is very little that is environmentally sustainable about it."

The empirical findings of the study have uncovered that cultural barriers both among consumers and companies are the primary obstacles to transitioning to a circular economy. Many interviewees believe that producers and consumers are not sufficiently drawn to green business practices due to a lack of knowledge and understanding about the concept of circular economy. This lack of awareness is also evident in institutions, as one interviewee noted:

> "A productive activity that starts from a by-product is still mistaken for a waste disposal activity. It's a waste of time and funds for us to prove otherwise."

Several key informants mentioned that local consumers in Sicily are not fully aware of the importance of circularity in their purchases and are less interested in environmental issues compared to foreign

consumers, particularly those from Northern Europe. Millers who implement re-use practices typically do so to comply with existing regulations, yet they frequently remain unaware that such actions align with principles of the circular economy. Paradoxically, this oversight often results in their focus solely on the costs associated with these practices, rather than recognizing the environmental benefits they entail. For instance,

> "*We dispose olive mill wastewater in compliance with the current regulations because, if not well managed, it is a polluting substance. This involves a cost borne by the oil mills themselves*."

Despite sustainability awareness is increasing, there is still a knowledge gap in Sicily regarding the circular economy concept, leading to informational asymmetry. Producers and consumers have limited understanding of the environmental impacts of products, resulting in undervaluation. Statements such as

> *"The producer only requires the milling service and does not care about the remaining 85 % of the product"* and *"Companies need to know what they can do, and knowledge should be disseminated about what can be done with their by-products and the economic benefits of investments"*

exemplify this trend. Consistently with Kirchherr et al. (2018), cultural barriers, including a low inclination toward associationism, are the most significant challenges for most qualified informants. Southern Italy struggles with cooperation among farmers along the supply chain and aggregation difficulties, which are seen as intrusive to their business models and detrimental to the competitiveness of the entire chain. As one interviewee highlighted,

> "There are no examples in Sicily of cooperatively managed oil mills, unlike what happens in the field of horticulture."

Breaking down inter-company boundaries and promoting the creation of new synergies where waste from one organization becomes a resource for others is considered essential.

Despite the theoretical potential for industrial symbiosis to reduce costs and foster a shared cluster of knowledge, the investigated supply chain still lags in practical implementation (Hamam et al., 2023). The system appears to be grappling with breaking free from established patterns, potentially due to the advanced average age of its actors. Although some statements express a willingness to introduce more radical innovations, companies involved seem temporarily oriented toward settling into the comfort zone and preferring incremental changes within the existing regime. The advanced average age of Sicilian farmers often leads to low competitiveness and a reluctance to embrace innovation. Therefore, the impact that generational turnover could have on overcoming cultural obstacles remains to be seen.

5.3. Innovation niches

The framework mentioned above sheds light on the challenges faced by Sicilian companies in their efforts to embrace circular economy practices. However, the literature on transition acknowledges that regimes can be influenced by emerging niches. Even a few entrepreneurial activities that demonstrate disruptive innovativeness can create a niche that can bring about a change in the existing regime. Interviews with key informants have revealed that, within a largely static landscape, signs of change are starting to emerge.

Among the practices being adopted, the agronomic use of olive pomace as a soil amendment appears to be the simplest and most widespread. One interviewee states,

> "I don't have any scientific data yet, but I can tell you empirically that in the treated areas the difference is visibly clear: the leaves are much more turgid, the plants are bursting with health."

Another noteworthy innovation is the transition of many oil mills from three-phase processing systems to two-phase systems, which reduces the challenge of wastewater disposal. While these innovations are incremental improvements in environmental practices, there are also pioneering experiences introducing more far-reaching innovations that could impact the existing regime.

For example, despite the challenges of collection and transport costs, olive pomace is being used in biomass digesters for biogas production, while the pellet of pit is being recovered as an eco-sustainable alternative energy source. Additionally, experiments are being conducted to extract polyphenols from wastewater for the production of pharmaceuticals, functional food, and beverages. Producers are also utilizing dried olive pulp as a supplement in high-quality animal feeds, leading to positive effects on animal welfare and the quality of derived products.

5.4. Potential strategies for transitioning towards a circular economy

During the second session of interviews, participants articulated a prevailing perspective regarding the transition toward a circular economy in the Sicilian olive oil industry:

> "a collaborative and holistic approach is imperative to successfully guide the transition toward a circular economy in the olive oil industry in Sicily,"

According to the insights provided by this group of key informants, targeted interventions encompassing regulatory frameworks, economic incentives, educational initiatives, and awareness-raising campaigns are deemed essential. These strategies aim to foster an environment conducive to the development of circular practices, thereby facilitating the establishment of a more sustainable future for both the olive oil industry and the broader environment.

Additionally, Fig. 5 summarizes the potential strategies for transitioning to a circular economy in the agri-food sector.

Renewed sensitivity, informative campaigns, technical training at all levels, and communication regarding the opportunities inherent in circular business models are essential.

The findings of the study underscore the critical importance of investing in education and awareness-raising efforts among both producers and consumers. Such endeavours can be achieved through focused educational campaigns elucidating the benefits of circular economy practices, emphasizing realistic timeframes for implementation, and catalysing a cultural paradigm shift towards sustainability.

The cultural dimension emerges as a central theme among the interviewees, highlighting the necessity of a fundamental shift in values towards embracing the principles of the circular economy. This finding aligns with the observations made by Kirchherr et al. (2018) and Mäkelä et al. (2022). Interestingly, the results diverge from conventional literature, which often adopts a technocentric approach to the circular economy, thereby overlooking its political and socio-cultural dimensions (Corvellec et al., 2022; Chembessi et al., 2021).

Training programs are essential for public sector personnel, often recruited through competitions dating back several years, as they may lack optimal efficiency due to age-related factors and limited familiarity with digital processes. This deficiency in attitudes and awareness among government officials is observed across various contexts, as noted in previous studies (Masi et al., 2018; Kazancoglu et al., 2021).

Furthermore, financial support measures are necessary to aid companies in this transition, as highlighted by interviewees. Despite recognizing the potential profitability in circular systems, many operators assert that current structural and operational costs are prohibitive. Therefore, adequate investment and incentives are indispensable.

A significant impetus could be a clear valorization of by-products emerged as a crucial aspect for companies during the interviews. Key informants stressed the need for a common direction that guides companies along the transition path and emphasizes the importance of by-products, as this phase cannot be managed independently by individual entrepreneurs (Valenti et al., 2023). If supported, entrepreneurs perceive an immediate economic motivation as an opportunity for

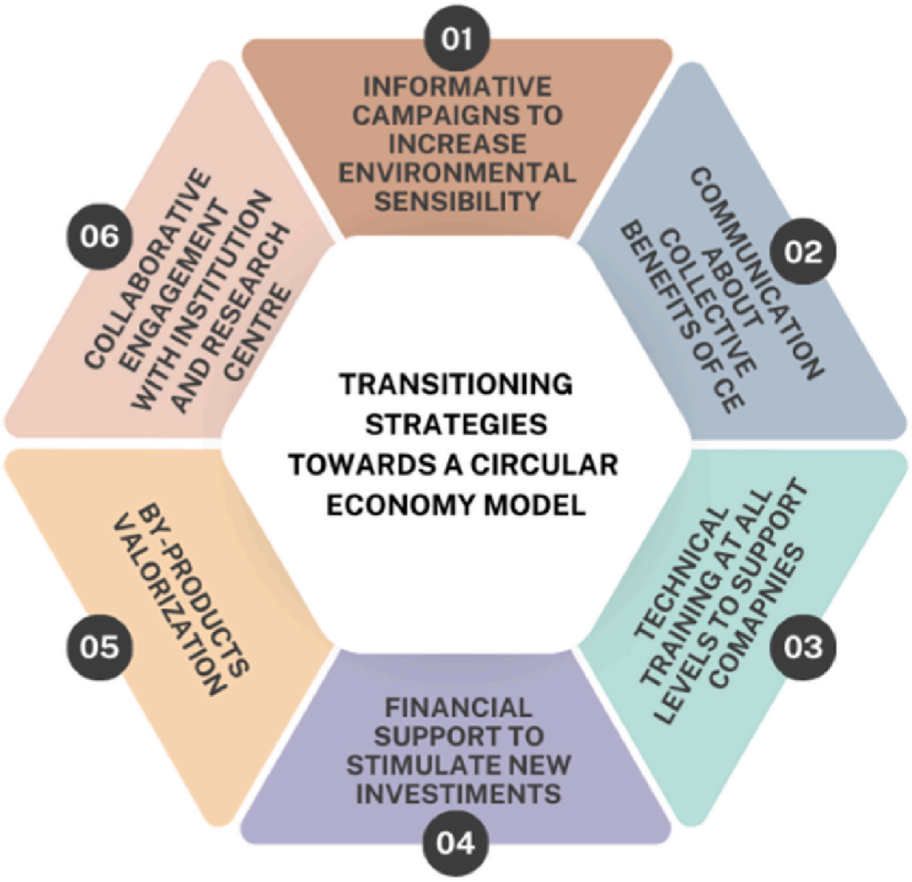

Fig. 5. Potential design strategies to move from linear to circular economy agri-food model.

development and cost reduction by valorising by-products. Initiating virtuous recovery processes, such as transferring to biogas plants or extracting polyphenols for nutraceutical products, was highlighted as essential by interviewees. These initiatives would ensure a new life for by-products, transforming them into resources for companies and the community alike. Additionally, interviewees noted a growing cultural sensitivity towards environmental protection and a willingness to meet market demands for environmentally friendly products that enhance brand image and corporate reputation.

Furthermore, the study's observations underscore the substantial contribution of networking. Collaboration with academia and other research entities, along with the policies of European institutions promoting sustainable production and consumption systems, plays a pivotal role. In fact, according to the MLP, achieving a transition depends not only on the presence of enlightened entrepreneurs but also on a plurality of actors who can build alternative visions and networks to align institutions, technologies, and shared practices (EEA, 2015; Jørgensen and Sørensen, 2002). In this context, pilot projects led by universities have been instrumental in pushing actors to create networks necessary for effective implementation of the transition, although studies on waste potential have stimulated entrepreneurial initiatives.

Apprehensions or resistance towards changes are prevalent among many businesses in the study area, particularly those managed by families, due to perceived inadequacy in coping with them. As emphasized by Teixeira et al. (2019), the support provided by networks such as universities and research centres assumes a fundamental role. These institutions can instil confidence and reliability among individuals embarking on the path of the circular economy by offering technical support, consultancy, and access to resources necessary for overcoming challenges and obstacles.

The significance of co-design and stakeholder participation in the development of circular solutions is paramount. Actively involving farmers, producers, consumers, and other stakeholders in the design of circular practices and business models can foster the adoption and dissemination of sustainable solutions.

6. Concluding remarks

The results of the conducted multilevel analysis could be read by resorting to the lens of the Hobbesian paradox of the ship of Theseus: a change which, as is the case of the mythological vessel (apparently remaining the same, despite the replacement of each single piece during the long voyage), is not immediately perceptible because of its slowness. According to this interpretation, the movements recorded at the niche level represent the first signs of an ongoing process that is destined to pave the way toward the full realization of the circular economy. What has just been stated may not come as a surprise to those who have already grappled with the general debate on the state of advancement of the circular economy: not unlike what happens to other sectors and supply chains, this analysis of the Sicilian olive oil sector has confirmed that the discussion on the relationship between circular economy, strategies, and outcomes is still open (Gavinelli et al., 2019).

In the context of this study, concerning the predominantly linear olive oil production chain, there are indications of progress. Niches are beginning to emerge, showcasing a shift in mindset among entrepreneurs towards environmental concerns and a heightened ability to adapt to the associated changes and sacrifices.

As Geels (2002) contends, transition is a gradual journey that demands time. Despite the prevalent discourse on circular economy, the concept has not yet matured into an established reality.

The path toward transition requires patience. The prevailing focus of contemporary culture on short-term gains and immediate solutions

hinders sustained progress toward sustainability. It is necessary to transcend this way of thinking and embrace a new paradigm of development. History provides ample evidence that significant social transformations, such as the industrial revolution or the establishment of democracy and liberalism, have required extended periods and the involvement of diverse actors. This historical perspective underscores the notion that transitions towards new societal paradigms, such as the circular economy, are multifaceted and protracted processes. Therefore, the transition represents a journey toward a future that will likely be witnessed by future generations. Yet, it also serves as a common guiding light, encouraging incremental steps in the desired direction.

CRediT authorship contribution statement

Daniela Spina: Methodology, Data curation, Investigation, Writing – review & editing, Writing – original draft, Visualization. **Massimiliano Borrello:** Conceptualization, Writing – review & editing, Supervision, Writing – original draft, Methodology. **Roberta Selvaggi:** Writing – original draft, Investigation, Writing – review & editing, Supervision, Data curation. **Gaetano Chinnici:** Writing – original draft, Visualization, Investigation, Formal analysis, Data curation. **Manal Hamam:** Formal analysis, Investigation, Data curation. **Luigi Cembalo:** Methodology, Resources, Validation, Supervision, Project administration, Conceptualization. **Mario D'Amico:** Validation, Supervision, Project administration, Resources, Conceptualization.

Data statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Submission declaration and verification

This work has not been published previously, and it is not under consideration for publication elsewhere. Its publication is approved by all authors.

Declaration of generative AI in scientific writing

None. The authors have nothing to declare for this manuscript.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2025.146130.

Data availability

Data will be made available on request.

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