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Agri-food systems in transition: Potentialities and challenges of moving towards circular models

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ABSTRACT

The Circular Economy (CE) has emerged as a paradigm for transitioning economic systems toward increased sustainability. The shift toward circular systems requires profound changes and presents challenges at various levels, involving a comprehensive overhaul of supply chains and systemic transformations. This paper focuses on the implementation of CE in the domain of agri-food systems, particularly analyzing olive oil production in the Apulia region, Italy. Gaining insights from the analysis of 14 key-informant interviews, eight aggregated dimensions resulted from data analysis, suited to describe the incumbent olive oil production system (structure and functioning, path-dependent mechanisms, bottlenecks, and lock-ins), its potentialities for circular transition (seeds of innovation, key design elements, enabling factors), as well as landscape forces exerting an external influence on the system (global or exogenous forces, adaptive answers). The multilevel perspective of socio-technical transitions was adopted as heuristic theoretical lens. This study represents a blueprint for future research on agri-food CE transition and contributes to orient sustainability transformations in the olive oil sector.

1. Introduction

Over the last decade, the Circular Economy (CE) has become a key paradigm for transitioning economic systems toward greater sustainability (Geissdoerfer et al., 2017), with the primary goal to operate within planetary boundaries while delivering societal needs. CE is highly resource-focused: its core idea is to alleviate environmental pressures by optimizing resource usage. This involves strategies based on sufficiency, efficiency and dematerialization (D'Amato et al., 2017), as well as closing, slowing, narrowing, or regenerating materials cycles (Bocken et al., 2016). Thus, CE offers a promising alternative to the conventional 'take-make-waste' economy, establishing restorative and regenerative models of production and consumption (EMF, 2015; Morseletto, 2020).

Despite the emergence of critiques (Korhonen et al., 2017; Skene, 2018; Corvellec et al., 2021), the quest for convergence around a final definition (Nobre and Tavares, 2021), and the call for a stronger integration with sustainable development (Velenturf and Purnell, 2021), CE continues to have a tremendous traction as a major transformational trend for reconciling economic and environmental goals. It provides a «deep transition framework» around which new sets of rules are emerging, aligning and diffusing internationally (Kern et al., 2020). Boosting a circular economy transition (CET) became a priority especially within the European Union, as witnessed by the rising policy frameworks and action plans striving for the adoption of circular models (European Commission, 2019, 2020a, 2020b, 2020c). Overall, CE is

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emphasized as a pivotal strategy to move into «a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gasses in 2050 and where economic growth is decoupled from resource use» (European Commission, 2019).

In this paper, we focus on CET in the domain of agri-food systems. Agri-food systems have a great potential for implementing a CE (EMC, 2015; Jurgilevich et al., 2016; Esposito et al., 2020; European Commission, 2020a), as they are major contributors to resource use in the consumer goods industry (EMC, 2013), and play a direct role in environmental management, being deeply rooted and interlinked with natural ecosystems (Vermunt et al., 2020). Reshaping agri-food systems according to a circular model would allow to generate virtuous metabolic cycles by reintroducing organic matter and nutrients into the biosphere, and to create new economic value through the recovery of residues and by-products.

Previous literature focused on the application of CE in specific agri-food areas, such as agricultural production (Hoof et al., 2024), food loss and waste (Principato et al., 2019; Santagata et al., 2021), and food packaging (Jäger and Piscicelli, 2021; Erhan et al., 2023). However, the trajectories along which CET may advance, and the related mechanisms of adaptation, are still unclear. A growing strand of literature analyzes the enabling role of new technologies or eco-innovations to drive CE (Muscio and Sisto, 2020; Böckel et al., 2021; Manal et al., 2022; Sánchez-García et al., 2024). However, CET goes far beyond the mere adoption of technological and/or organizational innovations, rather entailing profound transformation of supply chains and wider systemic shifts (Cembalo et al., 2020). This must pass through the design of new business models, the establishment of new intersectoral relationships, as well as broader changes in the infrastructural, cultural, and societal systems (Ghisellini et al., 2016). Therefore, transitioning into circular agri-food systems involves radical changes coevolving at multiple levels (Loorbach et al., 2017) and remains an open and uncertain challenge. Various kinds of structural barriers can hinder the transition process (de Jesus and Mendonça, 2018; Kirchherr et al., 2018; Mehmood et al., 2021).

As an effective CET needs to be properly stimulated, monitored and governed, focusing on the territorial specificities of agri-food systems is crucial. This implies understanding whether and how transition processes may advance starting from the current *status quo*, considering its evolving dynamics and bottlenecks, and deploying system innovations that could ultimately lead to a new equilibrium (Borrello et al., 2020). However, only few studies analyze how specific agri-food systems are facing the complex challenges of transition, based on a comprehensive understanding of the socio-technical system under investigation. To help bridge this knowledge gap, this study examines the olive oil production system in the Apulia region (Southern Italy) to gain empirical insights into the potentialities and challenges of transitioning this specific system towards a CE. More specifically, this study analyzes the fundamental elements underpinning CET by adopting as heuristic theoretical lens the Multi-Level Perspective (MLP) on socio-technical transitions (Geels, 2004). While previous studies have used the MLP to explore individual elements of agri-food systems, such as sustainable agricultural practices or alternative food networks, there is a notable gap in the literature concerning the comprehensive application of MLP to entire supply chains within the agri-food sector. Therefore, this study represents a blueprint for future analysis of CE transition in agri-food supply chains.

Moreover, this study is the first to analyze olive oil production through the lens of the MLP. The olive oil production system is an emblematic contextual opportunity to inquire CET in the agri-food domain. On one hand, this production system can be highly demanding in terms of resource consumption, and can generate important emissions, exerting significant pressures on the environment (de Gennaro et al., 2012; Banias et al., 2017; Neves and Pires, 2018). On the other hand, it generates huge streams of organic waste and by-products that have a great potential to be converted into valuable resources through circular processes (Berbel and Posadillo, 2018; Donner et al., 2022). Worldwide olive oil consumption is remarkably grown (Scheidel and Krausmann, 2011), triggering production to increase more than twice over the last three decades, and climb over 3 million tons per year (IOC, 2022). Olive oil supply chains are central in the agri-food system of the Mediterranean region, which houses 87% of worldwide olive groves (Hernández et al., 2018). More than 60% of the global olive oil production takes place in Europe, and Italy is the third largest producer in the world after Spain and Turkey (FAO, 2021). As for the selection of the geographical region of the study, Apulia is the leading olive oil producing region in Italy, accounting for over 50% of the national production (ISMEA, 2023). Apulian olive oil production has also a deeply rooted historical and cultural significance, offering insights into how long-standing industries can adapt to modern sustainability challenges.

This study seeks to answer to the following two research questions.

RQ1. What is the current configuration (socio-economic, technological, organizational, and environmental features) of the Apulian olive oil production system?

RQ2. What factors influence the transitioning of this production system into a more circular one?

The remainder of this paper is structured as follows: Section 2 provides a brief description of the MLP framework based on a review of relevant literature on the topic; Section 3 describes in depth the research methodology; Section 4 presents the findings of the study; Section 5 critically discusses the findings; Section 6 outlines some concluding remarks.

2. The Multi-Level Perspective on sustainability transitions

Sustainability transitions entail departing from an unsustainable present towards a new status in which pressing global challenges such as climate change, resource depletion, and social inequality, have been addressed (Markard et al., 2012). This necessitates substantial restructuring of the facets of society, encompassing industries, technologies, behaviors, and societal norms. In this domain, the Multilevel Perspective, as introduced by Geels (2002), has emerged as an invaluable tool. The MLP posits that sustainability transitions occur through changes and interactions among three levels: the niche, the regime, and the landscape. The niche serves as a fertile ground for innovation and experimentation that challenges established norms and practices embedded within the dominant regime. Meanwhile, the landscape encompasses the broader context within which these transformations unfold, reflecting societal, economic, and political dimensions shaped by cultural values, policies, and market dynamics. The MLP has been effectively deployed to scrutinize the dynamics of sustainability shifts across various industrial systems, such as those of energy (Geels et al., 2018; dos Santos Carstens & da Cunha, 2019; Gibbs and Jensen, 2022) or transportation (Figenbaum, 2017; Mazur et al., 2015; Nilsson and Nykvist, 2016).

The MLP has been used to inquire sustainability transitions also in the agri-food sector (El Bilali, 2019). While its application in this field hasn't been as extensive as in some other industries, the MLP is helpful to disentangle the intricate dynamics of change within agricultural and food systems, revealing both opportunities and hurdles. For example, the MLP has been used to investigate the adoption and diffusion of sustainable farming methods by analyzing the relationships among niche innovations, dominant regimes, and the broader agricultural context. Studies have explored how agroecological approaches, such as organic farming (Nuijten et al., 2018) and diversified cropping systems (van der Windt and Swart, 2018) challenge conventional agricultural practices. Additionally, the MLP shed light on the significant roles played by supportive policies (Levidow et al., 2014), innovation networks (Ingram et al., 2015), and the dynamic capabilities of firms (Gruchmann et al., 2021) in promoting sustainable farming practices.

Another field of application of the MLP has been the analysis of alternative food networks (Bui et al., 2016). These networks encompass elements such as farmers' markets, community-supported agriculture, and local food initiatives (Goodman et al., 2012) and often emerge as niche innovations within the food system. Researchers have uncovered through the MLP the driving forces and barriers influencing the growth and dissemination of these alternative networks. By dissecting the complex interplay among niche innovations, the dominant food system regime, and various landscape elements, including consumer preferences (Zagata, 2012) and policy frameworks (Wiskerke, 2003), they have generated valuable insights into the potential of these alternative food networks to reshape the agri-food sector, guiding it towards greater sustainability and local orientation.

Furthermore, the MLP has been proposed to examine the application of circular economy (Cembalo et al., 2020). Researchers have focused on niche innovations that promote resource efficiency, waste reduction, and the establishment of closed-loop systems within agri-food value chains. For instance, studies have explored 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), including the utilization of bio-based or compostable materials, challenging the prevalence of single-use plastics. By comprehending the intricate interactions among niche innovations, prevailing regimes, and landscape elements such as consumer behavior and policy frameworks (De Rosa et al., 2021), the MLP offers valuable insights into the potential of circular agri-food systems.

Although previous studies have utilized the MLP to investigate these specific aspects of agri-food systems, there is a notable gap in the literature regarding the comprehensive application of MLP to entire supply chains within the agri-food sector. This study falls in this domain.

3. Methodology

In this study, we used a qualitative methodology to understand a multi-layered and complex issue such as the transition of the Apulian olive oil system towards a circular model. Qualitative research aims to produce vivid descriptions and fresh explanations of social phenomena within real-life contexts (Mason, 2002). The research methodology is inspired by Grounded Theory, which is concerned with generating theory from empirical data, in an interpretivist and constructivist perspective (Glaser and Strauss, 1999). Our research approach consisted in using qualitative data as a ground to develop inductively an informed theoretical model to describe or explain a social phenomenon, without using pre-existing conceptualizations (Strauss and Corbin, 1994). Primary qualitative data was collected by conducting in-depth interviews based on open-ended questions, which involved a sample of selected key-informants.

3.1. Data collection

In a qualitative approach, data gathering cannot be seen as a neutral procedure consisting in retrieving already available information, but rather involves a process of new data generation, in which the researcher is actively involved (Mason, 2002). In this view, qualitative interviewing has been enacted as a process of knowledge co-construction. In this process, the researcher is engaged in the immersive and iterative process of generating and interpreting data. Instead of merely collecting pre-existing information, researchers actively develop understanding and narratives through a systematic coding procedure, refining codes and ensuring robust data structure. This approach allows for a deeper engagement with the data, fostering a more nuanced and comprehensive analysis.

During the summer of 2021, a total of 14 key-informants were interviewed, including olive growers, olive millers, technical advisors, representatives of professional associations, producers' organizations, and consortia, as well as academic scholars. Some of the interviewees fill multiple roles and positions, knowledge levels, and expertise areas (see Table 1). Their selection was guided by a purposive sampling strategy based on two criteria: i) knowledge and experience heterogeneity; ii) full geographical coverage. The first criterion aims to ensure the maximum variability within qualitative data, by exploring the topics of interest from the widest possible diversity of viewpoints, thus involving actors with different characteristics, knowledgeable about the olive oil system from various expertise domains, and experienced with the multiple stages of the supply chain. The second criterion is meant to get insightful and comprehensive information about the whole region. Besides, the selection process was contingent upon the researchers' expert knowledge of the regional sector and its actor system, also building on their relationship portfolio to reach eligible participants.

Key-informants participated on a voluntary basis. They were first contacted, talked about the research project, and asked about their willingness to be interviewed and recorded, aware that the data would have been processed anonymously and in aggregate form. Before the scheduled meeting, they received an informative note about the finality of the interview, and the data processing policy (ex Art. 13 of the EU Regulation, 2016/679, GDPR). A formal informed consent was also taken at the beginning of each interview. Key-informants were interviewed following a flexible scheme based on a topic-centered protocol, articulated in different thematic areas identified through literature review. Half of the interviews were conducted in face-to-face manner, and half *via* videoconferencing, due to the COVID-19 pandemic. In both cases, particular attention was paid to avoid leading the witness. The interviewing process ended when the informative saturation point was reached, while having pieced together a multi-stakeholder view. Each interview was recorded and then transcribed. About 15 h of video/audio recording and over 300 pages of transcripts were overall collected.

3.2. Data analysis

Qualitative data was approached through an inductive process of conceptual ordering (i.e. organizing a continuum of information into

Table 1
Overview of the interviewed key-informants.

ID	Profile description	Geographical coverage
i#1	Academic in the scientific sector of agricultural economics and rural appraisal	Entire region
i#2	Academic in the scientific sector of agricultural engineering	Entire region
i#3	Agronomist, representative of a PA[a] (province level) and senior technician for a PO[a]	Northern area
i#4	Agronomist, representative of a Consortium and organizer of an international organic olive oil prize	Entire region
i#5	Integrated olive oil producer and representative of a Consortium; former president of a PO[a]	Southern area
i#6	Integrated olive oil producer and representative of a Consortium; former vice-president of a District	Southern area
i#7	Integrated olive oil producer and representative of a Consortium	Northern area
i#8	Integrated olive oil producer and representative of a TA[a] (national level)	Northern area
i#9	Agronomist, quality manager of a Consortium, head panel of a PO[a], and international consultant for FAO	Entire region
i#10	Olive grower and representative of a POA[a] offering global services for the olive oil sector (national level)	Entire region
i#11	Olive grower and representative of a TA[a] (province level)	Southern area
i#12	Former division director and sales manager of a world-leading company in olive oil production lines	Entire region
i#13	Academic in the scientific sector of arboriculture and fruitculture	Entire region
i#14	Academic in the scientific sector of agronomy and field crops	Entire region

[a] Abbreviations: PA = Professional Association; PO = Producer Organisation; TA = Trade Association; APO = Association of Producer Organizations.

discrete categories) and cognitive development (Given, 2008). Qualitative analysis of textual data, such as interviews transcripts, consisted in a set of open, axial, and selective coding (Corbin and Strauss, 1990). In this process we engaged in an immersive work aimed at bringing order and making sense of the generated data, actively participating in developing understanding and narratives.

Preliminarily, a scoping analysis was conducted to map meaningful conceptual patterns from raw data. The interviews transcripts were exploratorily and independently read by two researchers with a purposive approach, searching for information relevant to the research goals. Then, to provide a robust data structure, the texts were systematically analyzed by using the software Nvivo, that facilitates handling and processing large qualitative data sets. Initial codes were derived directly from the interviewees' verbatim through a close line-by-line reading, and by labeling data segments basing on similarities and differences among the emerging "empirical concepts" (first order concepts). The naming of the labels was, as much as possible, consistent with the words used by interviewees. Then, empirical concepts relating to each other and referring to the same semantic area (e.g. a crucial issue, a relevant problem, a specific practice, etc.) were grouped into broader thematic categories (second order themes), which were comprehensive and mutually exclusive. Finally, the thematic categories were integrated into more general aggregate dimensions. While proceeding with consecutive coding stages, the original codes were iteratively refined. Some first and second order concepts were reconceptualized or combined to reduce complexity and consolidate the interpretative structure. To obtain more reliable results, a step-by-step procedure for data analysis and validation was followed, as detailed in Table 2. Initially, two researchers with different backgrounds were involved in data analysis, since a minimum of two viewpoints is required for investigator triangulation (Flick, 2006), adopted as collaborative strategy to accomplish convergent validation, completeness, and cohesiveness of qualitative findings (Archibald, 2016). Each researcher generated separately its own codebook, basing on the common guidance of the general conceptual patterns recognized during the scoping analysis. Then they came together to compare their results, discussing matches and discrepancies on content identification and codes definition. Since certain informants' statements rich in meaning could refer to multiple themes, the researchers sought for agreement on the most appropriate allocation. They also decided to handle minor dissonance between key-informants' perspectives by prioritizing consolidated common understandings. Other rounds of iterative analysis and discussion were repeated until achieving consensus and providing a congruent synthesis of the findings. Then, the data structure resulting from the former triangulation was subjected to validation by a larger group including four additional researchers. The validation process passed through independent reviews, collaborative discussion and deliberation sessions, and consensus building on the final set of codes and categories. Despite the inherent complexities and dynamics of group discussions, this structured approach ensured that the outcome was robust and reliable, benefiting from the diverse perspectives and expertise of the larger research group.

Following the above-described coding procedure, a total of 169 empirical concepts, 37 themes, and 8 aggregate dimensions were inductively identified (Gioia et al., 2013) (Fig. 1; see the supplementary material for more detailed information on the coding process). The aggregate dimensions were finally used as ultimate building blocks to picture the three analytical levels of the MLP framework which, therefore, has been used as a theoretical lens to frame, interpret and discuss the data. Since the levels of the MLP are predetermined by literature, the last conceptual ordering step was also guided by deductive inference.

4. Results

Following the MLP framework, the overall information has been organized in three distinct analytical levels, although declined in a more

Table 2
Step-by-step procedure followed for analyzing and validating data.

	Step	Description
Two researchers triangulation	**0. Purposive scoping analysis**	Two researchers read independently the integral interviews transcripts and took notes to identify emerging themes, conceptual patterns, and shared interpretations.
	1. Validation of a general interpretative framework	The two researchers came together to compare their understandings, integrate and corroborate them into a common interpretative structure, to be used as a general framework for guiding further analysis.
	2. Independent analysis (first-round)	Each researcher analyzed separately the interviews transcript on Nvivo, using its own analytical approach to define codes for the 1st order concepts. The whole textual data was broken down into minimum analytical units.
	3. Comparison and discussion (first-round)	The two researchers rejoined to compare the results of the first coding step. By discussing and scrutinizing together data segments, they eliminated redundant codes, agreed on the final allocation, and refined the codes' naming.
	4. Independent analysis (second-round)	Each researcher grouped separately the 1st order concepts into more abstract themes to form 2nd order concepts, and then distilled the latter into aggregate dimensions.
	5. Comparison and discussion (second-round)	The researchers came together to compare the results of the second and third coding steps. They discussed repeatedly how categories and sub-categories relate to each other against data, and revised the codes generated to best represent the data.
	6. Synthesis of the findings	The agreed-upon codes, themes and dimensions were assembled and synthesized into a cohesive data structure, which was anchored to the MLP to provide a synthetic analytical framework.
Six researchers triangulation	**7. Presentation of the findings**	The compendium of codes and categories developed by the two researchers was presented to the larger research group. Detailed summaries, along with representative data excerpts, were provided to ensure comprehensive understanding.
	8. Independent review	Each member of the larger research group independently reviewed the presented codes and categories, considering the alignment with the data and overall coherence.
	9. Collaborative Discussion	The group engaged in a structured collaborative discussion, that involved: **9.1** a **feedback session**, in which each researcher provided feedback on the initial codes and categories, highlighting areas of agreement and raising any concerns or alternative interpretation; **9.2** a subsequent **discussion and**

(*continued on next page*)

Table 2 (*continued*)

Step	Description
	deliberation session, in which the group discussed the feedbacks, debated different viewpoints, and addressed any discrepancies until reaching consensus.
10. Final validation	Once a consensus was achieved, the final set of codes was validated by the group, ensuring that it accurately captured the data and was methodologically sound.

nuanced conceptual structure to magnify the richness and extend of the empirical material: i) the incumbent olive oil system, namely the regime; ii) the potentialities for CET, emerging from the niches level; iii) the landscape forces on the background. For each level, the results are reported following backwards the coding pathway, from the aggregate dimensions to the empirical concepts grounded on raw data. Fig. 2 displays synthetically the results.

Source: our own elaboration from data, adapted from Geels (2002, 2019) and Borrello et al. (2020). Note: The three levels of the MLP represented in the Figure are described in the following main subsections (Regime: 4.1; Niches: 4.2; Landscape: 4.3). The other elements related to each analytical level are discussed in the second-level subsections: the structure and functioning of the regime in subsection 4.1.1; the elements of path dependency in subsection 4.1.2; the lock-ins in subsection 4.1.3; the seeds of innovation in subsection 4.2.1; the key design elements in subsection 4.2.2; the drivers, or enabling factors in subsection 4.2.3; the pressures and the windows of opportunity from the landscape in subsection 4.3.

4.1. The incumbent olive oil production system

The incumbent olive oil production system in Apulia is portrayed through three aggregate dimensions: i) structure and functioning; ii) strengths and weaknesses, that can be understood as the main outcomes of path-dependent mechanisms; iii) bottlenecks, that act as main forces in keeping the system locked-in.

4.1.1. Structure and functioning

The olive oil supply chain is a prominent component of the Apulian agri-food sector, with an important economic weight, and a great value as social, cultural, historical, and landscape-related heritage. Olive groves are widely spread throughout the whole region, which however is highly diversified in terms of morphology, pedoclimatic characteristics, socio-economic conditions, and local traditions. The interviewees agree in identifying four main olive oil producing areas, which differ according to plantations' features, cultivation techniques, olive varieties, olive oil qualities, and other peculiarities. The most important area is in the central part of Apulia, and it is characterized by rationalized plantations under efficient and intensive management. Most notably, the municipality of Andria, where « over 50% of GDP is earned from the olive oil production» (i#8), is identified as «the true engine of the Apulian olive oil production system» (i#4).

The Apulian olive oil supply chain is characterized by a variegated system of economic agents interplaying in different ways. First, there is a wide range of olive growers. Professional olive growers with a strong entrepreneurial approach oriented towards efficiency and profitability coexist with a plethora of non-professional producers (i.e. hobbyists or part-time workers), more tied to traditional practices. Besides, a plenty of extremely small farms, reflecting high land fragmentation, cohabit with large, specialized farms. The agro-industrial stage is also

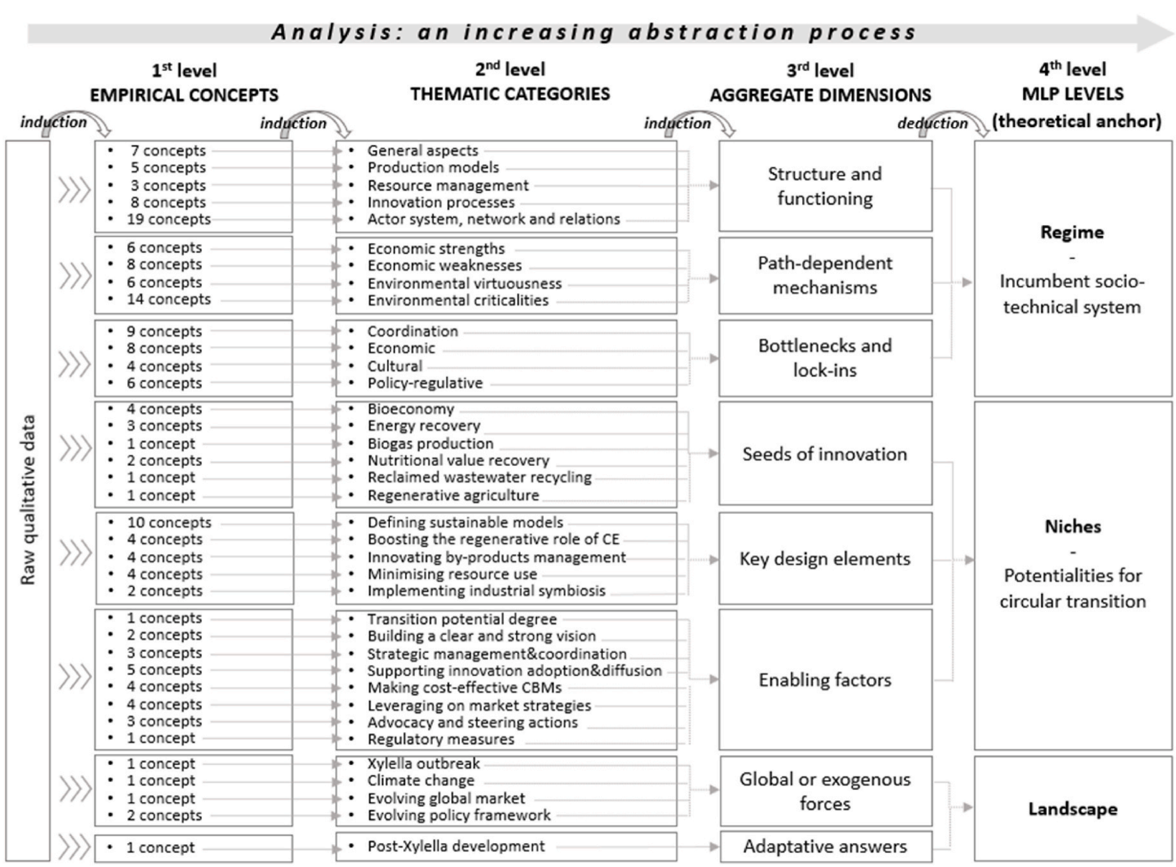

Fig. 1. Process of data analysis: consecutive coding stages.
Source: our own elaboration from data.

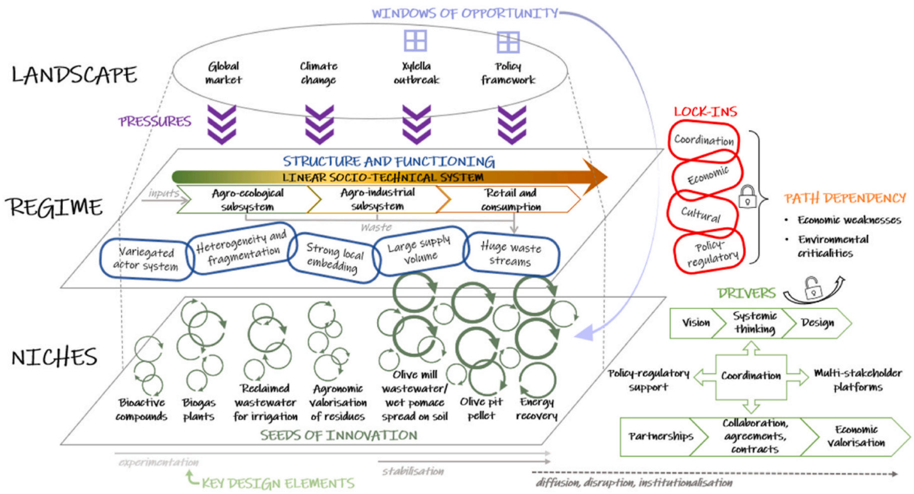

Fig. 2. Visual MLP map of the Apulian olive oil production system in transition.

heterogeneous and includes small and large mills. Three main typologies of olive millers can be distinguished: i) integrated millers, who primarily transform olives produced in their own farms; ii) specialized millers, who transform olives purchased from local olive growers, often through the mediation of trading brokers; iii) cooperative mills, processing olives supplied by its own members, namely hundreds of small/medium farmers. Specialized olive millers transform most of the olives produced in the region. Their relationship with olive suppliers is regulated by market mechanisms, in which the farmers have low bargaining power and act as perfect price-takers, while the millers set the selling price based on the volatile conditions of supply and demand. Instead, cooperative mills pay their suppliers at the end of the production season, depending on the total revenues gained from the sale of the produced olive oil. The final stage of the supply chain includes the activities of storage, packaging, and marketing. The interviewees strongly emphasized that most of the Apulian extra-virgin olive oil is sold in bulk to large bottling companies, usually localized in other Italian regions. These companies value Apulian olive oil for its intrinsic features (e.g. high polyphenolic content and intense taste) that make it ideal for blending with other mild olive oils to enhance their overall quality. In addition, key-informants remarked that a significant share of olive oil is kept by olive growers for self-consumption, as well as for direct sales, which remains a traditionally important distribution channel within the region. Nevertheless, two kinds of operators deal with storage, packaging and marketing activities: i) to a lesser extent, some olive millers complete the value chain, especially for high quality olive oils (i.e. organic, PDO, PGI) mainly sold on foreign markets or through e-commerce; ii) to a larger extent, a few specialized companies with huge storage capacity collect the bulk product from olive millers. These companies are characterized by very high bargaining power, so that they play a dominant role on the whole regional supply chain. Only in recent years some Producers Organizations (POs), which bring together several cooperative mills, succeeded in establishing consortium structures with significant storage capacity, enabling them to acquire a more balanced market position.

According to the interviewees, tradition and innovation coexist at all stages of the Apulian olive oil supply chain. In particular, the agricultural subsystem is still strongly linked to tradition, while the agro-industrial one is more dynamic in terms of technological renewal. Generally, the most advanced innovations are adopted by a minority of large firms, often managed by pioneering entrepreneurs with high-risk propensity. Starting from the agricultural stage, it should be noted that most of the Apulian olive groves are characterized by old trees (over 50 years) of autochthonous varieties and medium-low plantation density. However, during the last decades, several innovations have been extensively introduced to improve groves management by reducing costs and obtaining higher yields. Most of these innovations concern the mechanization of high labor-consuming cultivation practices, such as pruning and harvesting, as well as the adoption of more intensive olive growing models (high plantation density, use of more productive varieties, systematic and rationale use of agrochemicals, irrigation, and machineries). Passing to the olive processing stage, over recent decades Apulian olive mills have faced an epochal renewal with the complete replacement of the discontinuous extraction systems with the continuous ones, which allowed a significant increase of extraction yields, reduction of processing time, labor employment, and, in general, production costs. More lately, the two-phase extraction system (which separates olive oil from wet pomace) has gained popularity, gradually replacing the three-phase extraction system (which separates olive oil from dry pomace and wastewater), leading to significant water and energy savings. Newly emerging technologies (such as machines using ultrasounds, microwaves, pulsed electric fields, proto reactors, etc.) are still under development and testing. Lastly, in the storage and bottling phases, the most notable innovation of recent years is the use of nitrogen to extend the olive oil's shelf-life, better preserving its nutritional and organoleptic properties.

Regarding the management of by-products, key-informants emphasize that for a long time they were mainly considered as a serious problem for their disposal, rather than a resource with potential for exploitation. In general, the interviewees strongly agree that the olive oil supply chain generates massive volumes of different by-products. The agricultural stage mainly generates pruning residues and leaves resulting from cleaning olives after harvesting. In the past, these residues were simply burned, while today many farmers prefer to grind and bury them into the soil. Different kinds and amounts of by-products are generated at the milling stage, depending on the type of extraction technology in use. Specifically, in the case of three-phase plants, by-products are represented by dry pomace and wastewater: usually, dry pomace is conveyed to local refineries to extract pomace oil, while wastewater is distributed on farmlands. Instead, the unique by-product of the increasingly widespread two-phase plants, namely wet pomace, is not accepted by oil refineries due to its excessive humidity. Olive mills prefer to extract from it the crushed pits, which can be used as biofuel, while pitted wet pomace is ordinarily spread on farmlands.

4.1.2. Path-dependent strengths and weaknesses

One of the most cited economic strengths of the Apulian olive oil production system is the huge supply volume provided thanks to the large olive growing surface: «the region plays a major role at national level» (i#12), by contributing alone to about half of the Italian olive oil production. Moreover, the huge production capacity is coupled with high quality standards, mainly due to the favorable pedo-climatic conditions, the diversified panorama of autochthonous varieties, as well as the high professional capacities of entrepreneurs in both the stages of olive growing and milling. This unique combination of quantity and quality represents an exceptional production potential «that often lacks elsewhere» (i#4). However, despite its structural strengths, the Apulian olive oil production system seems to be unable to fully exploit its potential, mainly because of a low capacity to create and retain value. This is partly due to its fragmentation (high number of actors of relatively small dimensions), and to the lack of integration and coordination. As a result, reaching a satisfactory commercial valorization of products is challenging: «our main limit is that we are the best producers but the worst sellers» (i#8). In this regard, the most cited weakness is the poor exploitation of the territorial identity of Apulian olive oils. This could be better addressed, for example, by leveraging the geographical indications (e.g. PGI and PDO) which have been recognized to the region. Another important weakness is the structural lack of storage and bottling facilities, that forces the millers to sell their products to national traders quickly, during or immediately after the harvest campaign. This urgency negatively impacts the prices they can secure.

As regards environmental virtuousness, most of the key-informants agree in considering the olive oil production system not so impactful to the environment, especially if compared to other agri-food supply chains. They emphasize that, compared to other crops, olive growing requires a minor use of chemical inputs (pesticides, fertilizers), as well as of water for irrigation. In addition, more than 20% of Apulian olive farming is conducted through organic method. Many interviewees also highlight the outstanding environmental performance of olive farming in terms of carbon sequestration, «significantly higher than many other crops» (i#6). Besides, olive trees make a significant contribution in hydrogeological risk prevention, especially in hilly areas. Finally, olive groves are of primary importance as distinctive elements of the regional rural landscape. On the other hand, environmental criticalities are mainly related to the disposal of huge amounts of by-products generated by mills in a few months. The main critical issue is about the side-effects of spreading wastewater and wet pomace on farmland. When done improperly or repeatedly, this practice can generate serious problems of environmental pollution, and «negatively affect soil fertility in the long term due to cumulative effects» (i#14). Energy-demanding activities are also a matter of concern both at farming and milling stage (e.g. high energy consumption to withdraw irrigation water from deep aquifers). Another concern is due to water-related issues, in relation to both scarcity and management of water resources (i.e. overexploitation of groundwaters, and inefficient irrigation systems). High concerns are expressed about water consumption of intensive olive growing systems: «we have a dry land, and these olive growing systems need large water volumes for irrigation» (i#7). In summary, the olive oil production system «can be very environmentally sustainable, yet at the same time very polluting» (i#6) depending on the ways it is managed, and the «degree of compliance with the current environmental regulations» (i#2). Unfortunately, often «olive millers are tempted to turn to cheaper shortcuts such as releasing effluents into the sewer systems, or even in the aquifers» (i#1).

4.1.3. Bottlenecks and lock-ins

Key-informants identify various kinds of bottlenecks hindering the exploitation of the full potential of the regional olive oil production system. Integration and coordination shortcomings are widely reported. They are mainly related to the high fragmentation of the supply chain, that «creates great difficulties to coordinate a plethora of different economic actors and product flows» (#i1). In addition, there is a prevalence of individualistic, rather than cooperative attitude, which probably derives from the fact that «historically there haven't been successful experiences in the cooperative sector» (#i6). In particular, «there is a poor connection between farmers and millers» (#i4), and the «shortage of mutually binding trust between these two parties» is identified as one of the most deleterious bottlenecks (#i12). Lack of integration and coordination is also detected between the millers and the last link in the supply chain, that includes storage, packaging, and marketing activities. This results in the «inability to build a shared strategic vision» (i#14) and to develop common marketing strategies, especially for the valorization of high-quality products. In short, the interviewees strongly express a need for a greater integration and a better coordination of the supply chain: «it is necessary to identify the right models, the right scales, in the right contexts, and this is a matter of organization», or in other words of «piecing together the pieces that already exist» (#i6).

Another important bottleneck identified is the gap between research institutions and the production system, so between «who generates innovations and who should use them» (i#13). Research activities often do not properly comply with the real innovation needs of the production system and fail to perform an effective technology transfer. So, despite there was not lack of funding for research activities, «the adoption of innovations is very limited» (i#1). This is further exacerbated by cultural inertia of entrepreneurs, and a diffused resistance to novelty: «in the olive oil sector any new idea requires many years, or decades to be implemented» (i#12).

Finally, on the policy-regulative side, the interviewees highlight the need for a more effective governance and institutional planning, especially at regional level: «the role of the Public is essential» (i#6). A relevant issue is related to unclear regulations about by-products management, that often do not allow discriminating correctly by-products from waste, with detrimental effects for recovery and valorization options: «if by-products are treated as waste, they must be disposed at very high costs» (i#8).

4.2. Potentialities for circular transition

The potentialities for transitioning the Apulian olive oil production system into a CE are portrayed through three aggregate dimensions: i) seeds of innovation, namely the operative ways for applying CE principles that are already available or emerging at the niche level; ii) key design elements that should be considered for implementing and further developing circular niches; iii) enabling factors that can contribute to drive and accelerate the transition process.

4.2.1. Seeds of innovation

Key-informants identified several circular solutions that are technically validated or already implemented at the niche level. A first option is extracting high value-added compounds from mill wastewater (e.g. polyphenols and other bioactive compounds) and olive leaves (e.g. chlorophyll or oleuropein). These substances potentially have a great commercial value for relevant applications in pharmaceutical, nutraceutical, cosmetic, and feeding stuff industries, which are «increasingly oriented to substitute synthetic ingredients with bio-derived equivalents» (i#6). Downstream to the extraction of bioactive compounds, mill wastewater can undergo a mechanical filtration obtaining ultrapure water (safely useable for irrigation) and solid residues (employable as fertilizer). However, «this pathway is still little exploited» (i#4) and could represent a frontier to reach «in the next 10 or 20 years» (i#6). Currently, there is only one Apulian startup extracting from mill wastewater a patented polyphenolic compound for dermo-cosmetic and food supplements uses.

The most cited, and apparently most promising circular pathway is the production of biogas through the anaerobic digestion of olive mill by-products, specifically wet pomace deriving from two-phase extraction systems. The biogas can be used to generate electricity, heat, or biofuel, while liquid and solid residues (i.e. digestate), containing highly decomposed organic matter, can be employed as soil conditioner/fertilizer. Such solution allows to recover both the energetic and organic value of olive mill by-products, and to establish regenerative loops in the biological cycle. Biogas plants fed with olive mill by-products mixed with other agricultural residues are «already consolidated experiences» (i#1) in Apulia: «they represent an important alternative for some mills, that otherwise would have serious problems to manage their by-products» (i#14). Currently, in the region there are also two innovative plants exclusively fed with olive pomace. Today producing biogas only from olive pomace «is absolutely feasible» (i#2) because the technology is ready. The potential of this pathway is «enormous» (i#9), considering the large volume of olive mill by-products available in the region. However, it should be noted that the simple recovery of energy from olive oil by-products and residues is a consolidated route. For instance, pruning residues and exhausted pomace are often used to feed plants producing electricity power with combustion. Moreover, a growing number of mills separate olive pits, which are used as an excellent biofuel for boilers and stoves.

Many key-informants agree that another interesting circular pathway is related to the use of treated urban wastewater for irrigating olive groves. Reclaimed wastewater is increasingly considered as a safe and sustainable source of water for irrigation, «especially in areas characterized by a chronic scarcity of conventional water resources, as in the case of the Apulia region» (i#1). Such effluent also represents a diluted fertilizing solution that could ensure a supply of nutrients to the crops, thus reducing the use of fertilizer inputs. According to key-informants, «olive crop lends itself perfectly to agronomic application of reclaimed wastewater» (i#4) since the absence of direct contact with the fruits minimizes contamination risks. However, although there are already some virtuous cases enacted in Apulia region, the current recovery of urban wastewater is far away from its huge potential.

The circular pathways acknowledged by key-informants are well aligned with those encountered for the olive oil sector in the literature, according to a scoping review conducted by Stempfle et al. (2021), and mapped in Fig. 3 basing on the CE diagram proposed by EMF, 2013. This review identifies available pathways for reshaping the olive oil supply chain from a circular perspective based on studies across different disciplinary areas and geographical contexts.

It is worth noting that Fig. 3 is a positive CE model - i.e. it shows theoretically available circular pathways against seeds of innovation actually in place - rather than a normative CE model - i.e. circular pathways that should be implemented.

4.2.2. *Additional key elements for a circular design*

Besides reporting what is happening at the niche level, the interviewees identified additional key-elements that should be considered for designing circular business models within the olive oil supply chain. For the farming subsystem, a crucial issue is the consolidation of regenerative farming practices aimed at preserving and improving soil fertility: «taking care of the organic matter cycle remains a central issue» (i#4). Agricultural residues «should be preferably reintroduced into the agro-ecosystem» (i#1) to enhance biological metabolism. For example, pruning and harvesting residues should be incorporated into the soil to restore its organic matter content. In addition, particular attention should be paid to the practices that allow looping back to the olive groves the organic by-products obtained from the milling stage (e.g. pomace or, better yet, digestate). Another remarked aspect is moving away from agro-chemicals (e.g. pesticides and fertilizers) and switching to bio-based alternatives. This can be achieved by further incentivizing the adoption of organic methods of cultivation, or of selected alternative methods for the control of the main pathogens, especially olive fly (*Bactrocera oleae*). In addition, chemical weeding should be replaced by controlled grassing, which is a virtuous practice to improve soil fertility. The interviewees also emphasize the importance of precision farming for reducing the use of inputs, by ensuring timely and localized interventions for pest control, fertilization, and irrigation.

As for the agro-industrial subsystem, most of the key-informants highlight the need to reduce water and energy consumption, according to improved efficiency criteria. They also point out the pivotal role that olive mills can play for developing multiple circular solutions: «the mill has the potential to become an integrated platform, or a bio-refinery, able to recovery most of by-products through cascading uses» (i#14).

4.2.3. *Enabling factors*

Although most of the interviewees argue that CE has not yet become a mission among farmers and millers, they claim that the olive oil supply chain has a great potential to move towards a circular model. They highlight several enabling factors to boost the transition process. The

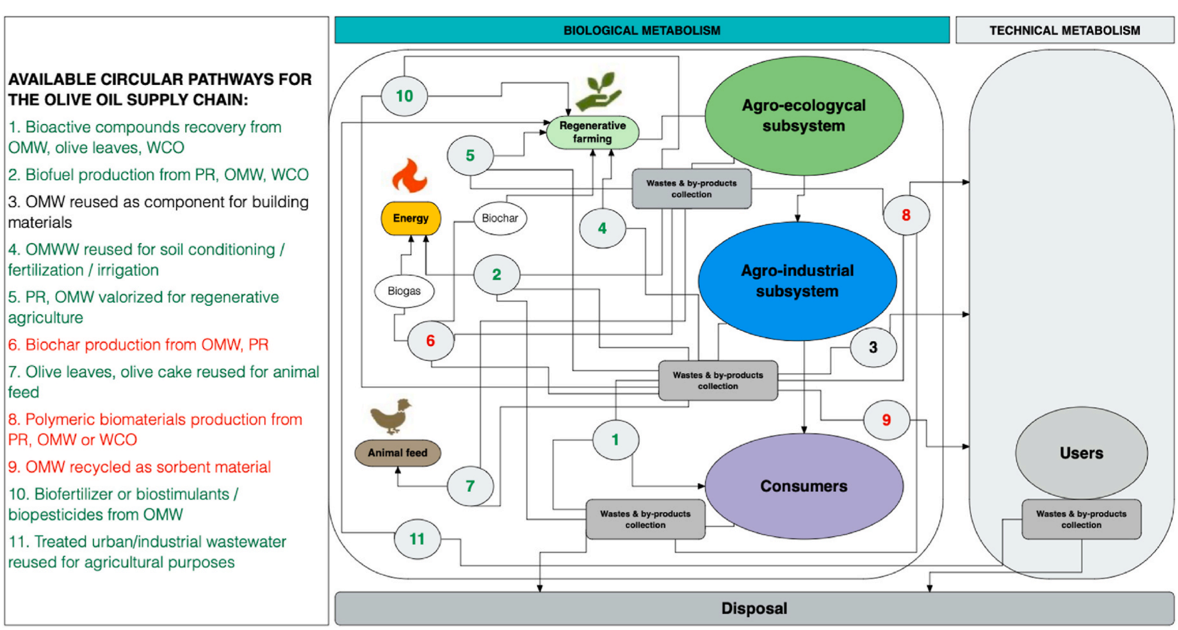

Fig. 3. Seeds of innovation identified by stakeholders compared to a theoretical circular Economy (CE) model for the olive oil supply chain.
Source: adapted from Stempfle et al. (2021). Note: in green the circular pathways already applied in the Apulia region; in red those that are proposed by literature but not mentioned by key informants; in black a circular pathway mentioned but still not applied. Acronyms: Olive Mill Wastes (OMW), Waste Cooking Oil (WCO), Olive Mill WasteWater (OMWW), Pruning Residues (PR).

most remarked one regards the development of suitable strategies to valorize olive oil produced according to CE principles. Given that «economic sustainability is an essential pre-condition» (i#6), higher economic results to the firms involved in virtuous practices would be a crucial incentive for adopting circular business models. Farmers and millers «are sufficiently open to change their way of doing, if they are compensated by fair economic rewards» (i#12). Differentiating the products by using a kind of label attesting high degree of environmental sustainability and circularity may allow the firms to «gain a premium price on the market» (i#10). This clearly entails also establishing a proper certification scheme to give «guarantees to consumers» (i#12). However, there is a «need for a deep reflection about certifications» (i#17). In fact, from one side, the increasing multitude of labels risks «overwhelming the consumers » (i#14), on the other side, the high certification costs could hinder a widespread implementation.

Key-informants also agree that one of the most important factors to boost CET is a better integration and coordination of the whole supply chain. This is very relevant especially in view of the current supply chain configuration, characterized by a wide number of different and disconnected actors. Key-informants point out that to build a robust circular supply chain it is necessary setting up collaborative organizations, overcoming the individualistic logic of «everyone find a solution by himself», for moving into a collective way of thinking, better if based on «a common territorial scale, such as that of districts» (#4). District-like strategies are paramount to realize economies of scale. For example, to strengthen the circular niche of biogas production «it could be envisaged a couple of plants serving the central area of Apulia, gathering the massive volume of by-products from all the mills operating there, and from which farmers could take back the digestate to be used as fertilizer: this would truly become a circular closure» (#10). To pilot the adoption and diffusion of circular innovations, it has been highlighted also the centrality of training and field demonstrations of good practices (#1), as crucial elements of research and technology transfer (#12). Last but not least, another enabling factor would be represented by a regulatory review: new measures should be introduced, firstly, to discriminate between waste and by-products, secondly, to ease the recirculation of agricultural residues and industrial by-products within and across economic sectors.

4.3. Landscape forces

The exogenous factors pointed out by the interviewees refer to the market and policy scenario, climate change, and, above all, the Xylella outbreak. While the first two elements are significant at international scale, the latter is mainly acting at the meso-level (i.e. the regional context).

Starting from the olive oil market, its evolution gave rise to a few difficult challenges. First, the olive oil market has begun «globalized, extremely volatile, governed by a multiplicity of factors that are not easy to predict» (#1). The Apulian supply chain must face a «turning point», especially because it suffers from the competition not only with Spain (i.e. the main competitor country of Italy), and the recently emerged North-African basin (above all, Tunisia), but also with «new countries that are becoming established on the global scene, such as Chile and Australia» (#14). The huge production potential of these emerging competitors risks marginalizing the Italian olive oil sector, both in productivity and economic terms. Some of these competitors can rely on important economies of scale and low production costs, especially due to «the differential in energy costs» (i#7), that result in lower final prices. Besides, another threat comes from a process of commodification that tends to present olive oil «as a mere fat, rather than a specialty food product»: if olive oils are homogeneous worldwide, then «the winning one is the cheapest» (#7).

In key-informants opinion, the evolving policy scenario can favor a CET of agri-food systems: «sustainability and CE have become pivotal policy cornerstones within the European Union, the Italian Government, and local institutions» (i#5). Although at the national level there have been an attempt to «by-pass and postpone normative compliance» rather than addressing a real transition, many firms have already put sustainability at the heart of their development processes, and those who are not «will find themselves out of the market, and of the upcoming regulations» (i#7).

Another relevant landscape force is climate change, whose effects in terms of high temperature, altered precipitation patterns, and desertification are increasingly experienced along the whole Apulia region. Some key-informants highlight that this is worsening chronic environmental problems, such as soil degradation, and may have direct economic consequences owing to olives production losses. It was brought an example of how an intense heat wave occurred «during the allegation period, burned the early fruitlets of a sensible olive variety» (i#4).

Finally, at regional level, an important exogenous factor of phytosanitary nature is severely impacting the olive oil supply chain. It is due to the outbreak of *Xylella fastidiosa*, a pathogenic bacterium that cause the quick desiccation and the death of olive trees. It was firstly detected in South Apulia in 2013, and it reached rapidly epidemic proportions. Since no cure has been found so far, during the last decade thousands of hectares of olive groves were lost in the infected areal, where «there is practically no more olive production», and «about 80% of mills closed down» (i#11) or «drastically cut their production capacity» (i#5). The magnitude of this phenomenon is reflected in the interviewees' words associated with the Xylella outbreak, perceived as a «tsunami», a «tragedy», a «catastrophe». High concerns were also expressed about the gradual expansion of the pathogen along the whole region, and the risk of compromising the entire Apulian olive oil sector. In summary, the olive oil supply chain in South Apulia «should be completely rebuild» (i#3) after the Xylella outbreak. Considering that «olive growing cannot be recreated in the short term» (i#8) it is still uncertain how, when, and to what extent it will be reconstructed. However, as the interviewees underline, the threat «can become a unique opportunity», that «has not been taken yet» (i#3), to rethink the production system and «rewrite the history of the territory starting from a blank sheet» (i#6).

5. Discussion

By means of qualitative interviews, an extensive cognitive framework was inductively carved out from the deep, experiential, and located knowledge of relevant key-informants of the olive oil sector of the Apulia Region, Italy. The outcomes were outlined into the framework of the multilevel perspective, assumed as theoretical anchor to discuss the CET process at hand. The MPL is a valuable framework for decision-making in systemic sustainability transitions. It supports policy planning, enhances the clarity and relevance of transitional foresight, and serves as a robust heuristic tool to navigate complex challenges (Wallace, 2021). In this study, the MPL allowed to map the Apulian olive oil production system in transition, and thus showing its lock-ins and path dependent dynamics, the potentialities for CET, as well as the landscape forces exerting influence on the system. This contribution is particularly valuable as it provides for the first time a longitudinal perspective of CET in the olive oil sector in this region, including factors potentially enabling a future diffusion, disruption and institutionalization of circular practices (Fig. 2).

First, the socio-technical regime was described by focusing on the structure and functioning of the olive oil supply chain, the main descending highlights and constraints, and the major lock-ins, including organizational, economic, cultural, and regulative bottlenecks which generate many dysfunctionalities at economic and environmental level (i.e. the two main dimensions of CE). While perpetuating a certain way of thinking and doing things that contributes to consolidating the current regime and its path-dependent trajectories, they also generate internal tensions along the supply chain, representing potential elements of instability in the dominant system.

As for the niche level, many solutions that can be framed under a CE model were acknowledged. Some of them are already entrenched into the incumbent regime and were historically enacted, or more recently developed. This is in line with the argument that even a linear system can include some elements of circularity, although not always deliberately (Lewandowski, 2016). However, the adoption of circular practices is still quite jeopardized, eventually rising from individual decision-making, rather than propelled by a systemic reconfiguration process: it is mainly pursued by individual actors who have the knowledge, capacities, and value orientation to adapt, innovate or design new business models. Besides, such practices seem to be more related to waste management concerns, rather than to integrated approaches consistent with a CET. This is in line with Govindan and Hasanagic (2018), who found that a primary driver for enterprises to implement the circular economy is that they must keep within current laws for waste management. Economic factors (i.e. reducing waste management costs or recovering value from by-products) appear to be the strongest motivations beyond the adoption of circular practices because, as stressed by key-informants, economic sustainability remains a main challenge for producers. This is in line with Mehmood et al. (2021), whose review indicates financial and economic benefits as major drivers for CE implementation in agri-food supply chains. Accordingly, Govindan and Hasanagic (2018) state that business actors are particularly motivated to implement circular economy practices due to the anticipated financial benefits across the supply chain. As many enterprises are profit-driven, the potential for increased profitability makes the circular economy an appealing option, often prioritizing financial gains over environmental impacts.

From a life-cycle perspective, useful to better understand the whole transition stage (Kanger, 2021), the niche level is in an initial stage of emergence. What we called 'seeds of innovation' towards CE are developing at different degrees of structuring and speeds, and do not seem sufficiently aligned to each other to quickly reach the upscaling phase. Overall, a technocentric approach to CE implementation seems to prevail. Since the availability of technical solutions is crucial for adaptability and the development of a circular economy, technological challenges are considered a major barrier to this transition and academic literature still emphasizes the importance of technological innovation in facilitating the transition to a circular economy (de Jesus and Mendonça, 2018). However, while many technological innovations are already mature and ready to be adopted, the social and organizational innovations that would allow the constitution of circular supply chains (e.g. networks or mutual relations to exchange resources and allow loop closures) are still weak.

Besides the existing circular practices, a few relevant key-elements for designing circular business models and supply chains did emerge from the interviewees' discourses. Distinct claims were advocated to implement CE specifically into the agro-ecological and the agro-industrial subsystems, while some overall, transversal strategies were identified. The role of design is essential to forge a circular system. It could provide a coherent framework to reconnect the emerging niches and develop new ones within integrated approaches and systemic thinking, that are currently missing. However, to address robust innovation patterns and guide fundamental changes, the design should be grounded on a clear long-term vision of CE. As the interviews reveal, a definite and shared vision of CE, that could provide a base for design, has not yet been matured. Circular futures will be nebulous if the CE remains a general goal, but an essentially contested concept (Korhonen et al., 2018). So, how a circular agri-food system may be modeled by design will also depend on the specific meaning and narrative of CE that will prevail, among the divergent ways it can be conceptualized (Bauwens et al., 2020). According to Friant et al. (2020) many ontological interpretations coexist in the discourses about the CE, with varying substantial implications on social, economic, and ecological aspects. Thus, the route along which CET could advance in the Apulian olive oil production system will also depend on how CE will be conceptually framed, as well as from the relations of power among the agents interacting in the co-construction process. Moreover, the design should be context specific. As argued by key-informants, a unique solution for circularity does not exist, and different implementation models should be fashioned considering the various territorial and socio-economic settings across the region.

Enabling factors to boost the transition process have also been highlighted, and they are somehow specular to the bottlenecks identified at the regime level. This means that the same obstacles that are currently precluding further advancement in the regional olive oil sector coincide with the barriers that may prevent the changes required for CET, potentially leading to a lock-in situation. The more relevant barrier seems to be related to the limited organizational and coordination capacity, especially considering that «transitions in socio-technical regimes are situated at the level of organizational fields» (Geels and Schot, 2007). Consistently, Grafström and Aasma (2021) identified weak cooperation throughout the supply-chain as a major barrier for CET, as business actors may deem CE measures intrusive on business models, not economically beneficial and hampering the competitive nature throughout the supply-chain. Moreover, even if a company is willing to endorse the CE approach, this does not necessarily mean that its supply chain is also willing to embrace it (Kirchherr et al., 2018).

In the background, exogenous forces operating at the landscape level, out of local actors' direct control, may affect the socio-technical transition. Such kind of forces can exert significant influence on the system re-configuration, with outcomes that can vary depending on the responses from both the regime and the niches. Thus, landscape forces can act as reproducing apparatuses that strengthen the regime, or alternatively as windows of opportunity for catalyzing a CET. In particular, EU's political and regulatory frameworks provide both directionality and structural opportunities to steer CET, but they need to be translated into policy instruments and actions at local level (Barquet et al., 2020; Galli et al., 2020). In general terms, there is agreement in the literature on the role of the government at various levels to foster CET. Public decision makers are deemed fundamental to support companies with economic incentives to deal with the high upfront investment costs, to create a conducive and harmonized legislative and regulatory environment (de Jesus and Mendonça, 2018; Govindan and Hasanagic, 2018; Kirchherr et al., 2018; Grafström and Aasma, 2021; Mehmood et al., 2021; Geissdoerfer et al., 2023)

Climate change and global market instability are also putting great pressures on the regime, unveiling some structural weaknesses, and calling for a deep strategic reorganization of the supply chain. On one hand, the worldwide agricultural sector is already under strain to fulfill the increasing need for food and energy, but it is facing additional challenges due to temperature rise, variations in rainfall, and extreme weather patterns. Therefore, the CET may be strategic to ensure environmental protection and preserve the resilience of crop productions (Mehmood et al., 2021). On the other hand, current trends on price volatility are often emphasized as drivers of new, more sustainable and circular economic models (de Jesus and Mendonça, 2018).

Circular niches may take advantage of these pressures, as long as they show to bring improved resource management, economic benefits, and higher systemic resilience. However, the most disruptive change is the specific shock of the Xylella outbreak (Bozzo et al., 2022). Having dismantled part of the regional olive oil production system, it offers a unique opportunity for rebuilding, experimenting, and shaping a circular model that could be a reference point for the entire agri-food system. The key elements for circular design and enabling factors evidenced by the interviewees represent a first guidance for informing this process, that however should be advanced within dedicated design sessions, possibly with larger participation of the stakeholders.

We argue that many circular pathways may develop around two main emerging transition trajectories: industrial ecology and regenerative agriculture. Most of the circular pathways pointed out by key-informants and nested in the aggregate dimension "seeds of innovation" (e.g. bioeconomy, energy recovery, biogas production, nutritional value recovery, see Table 1) pertain to industrial ecology, namely an approach of industrial design seeking to optimize the material cycles and evolve towards a cleaner production, by closing loops, reusing any available source of material or energy, minimizing raw resource use, and eliminating waste generation. However, so far, the innovative niches seem unable to develop into more complex systems of industrial symbiosis (i.e. one of the key design elements indicated by key-informants). The remaining circular pathways explicitly evoke the concept of regenerative agriculture, which is also recalled among the key design elements related to establishing sustainable models of olive growing, and to valorizing the crucial role of agriculture in regenerating and restoring the natural capital. Following the institutional perspective advanced by Plumecocq et al. (2018), the former trajectory appears more aligned with the conventional value-system (i.e. productivism, efficiency, technological mastery) and can generate an incremental transition, mainly based on technological and organizational adjustments of the regime architecture. Instead, the latter trajectory may mobilize radically different values (e.g. an alternative relationship with nature, disconnected from industrial and market capitalism) that question the very foundation of the *status quo* and can lead to a disruptive transition type, involving changes in modes of production, social relationships, and institutional norms. Thus, it could find a greater regime resistance to change. However, the importance of regenerative agriculture is extensively addressed by some of the key-informants. The particularity of the agri-food sector, that makes it completely different from any other economic sectors, is that its production structure completely relies on biological processes. Xylella itself is a biological threat. This has at least two implications. The first is that implementing CE in the agri-food domain should follow a radically distinctive rationale: for instance, product design cannot play a relevant role as in sectors based on technical cycles, since the production processes and outputs are strongly affected by environmental conditions. Instead, as pointed out by key-informants, innovating the ways of using and valorizing by-products is a crucial strategy. The second is that, more than other economic activities, the agri-food sector can truly contribute to restore and regenerate the ecosystems in which it operates (i.e. one of the fundamental principles of CE according to EMC, 2013). This makes it particularly important rethinking the role of the agricultural sub-system for enabling virtuous biological cycles. In this respect, it is significant that the interviewees claim for the establishment of sustainable olive growing models.

6. Conclusion

This study contributes to advance our understanding of CET within agri-food systems, by providing valuable insights on the olive oil production system in the Apulia region. It also identifies specific path-dependent mechanisms and lock-ins unique to the Apulian olive oil sector, such as traditional farming practices, regional economic dependencies, and cultural factors that provide valuable lessons on overcoming similar challenges in other regions. Moreover, Apulia's innovative CE practices are tailored to its specific agricultural conditions, thus being able to inform other regions with similar agro-climatic environments.

Thanks to the three analytical levels drowned from the MLP framework, we were able to answer the initial questions: a wide overview on the current state of the system (RQ1) has been provided and thoroughly discussed. Besides, expanding the analysis to the regime lock-ins and the niches enabling factors, the challenges and potentialities of transitioning towards a more circular system (RQ2) have been exposed.

The main limitation of the study is due to the potential cognitive biases from which are not exempt interpretivist and constructivist research approaches, such as those guided by Grounded Theory. In fact, the results draw on the knowledge and interpretations brought by key-informants, further mediated by the expert understanding of the authors. Thus, individuals' distorted perceptions, inaccurate judgments, or heuristics may have led to misrepresent the description or explanation of some aspects of reality. However, the risk of cognitive biases has been addressed by enacting mitigation strategies: e.g. accurate purposive sampling, attentive to bring together different expertise areas and viewpoints; meticulous interviewing process; rigorous and systematic qualitative analysis, built on a stepwise coding procedure and corroborated through collaborative discussion.

A specific kind of bias may stem from the lack of integrative perspectives that could have been brought by other categories of key-informants. In this study, we primarily focused on stakeholders directly involved in the olive oil production system, given that the development of CE is believed to be strongly practitioner-led. We recognize that including public and private policy makers, such as representatives of public authorities and market demand sectors, would have enriched our analysis, providing a more comprehensive understanding of the transition towards a CE in the olive oil sector. Furthermore, future studies should consider the inclusion of capacity building and validation workshops to enhance the research approach and facilitate knowledge transfer to policy makers. This process should also integrate more recent developments of transition literature, analyzing how the seeds of innovation in the niche have the potential to overcome the lock-in mechanisms in the regime (Ingram et al., 2015; Wigboldus et al., 2016). Adopting a transdisciplinary approach in future research could further enrich the study by fostering collaboration among a broader range of stakeholders and ensuring the practical relevance of the findings.

Another limit of the study is that, referring to a particular production system in a specific context, the results cannot be generalized. When applying the same research protocol to other supply chains or territories, different ways of implementing CE and transition mechanisms can be found. Nevertheless, some relevant considerations of general interest for the whole agri-food sector can be derived.

First, we suggest that CE implementation should be addressed to meet the specificities of different production systems and related supply chain~~s~~ configurations, and should be targeted to the peculiar needs, socio-economic and environmental conditions of diverse local contexts. ~~Contrary to~~ Unlike the last radical agri-food system disruption, namely the Green Revolution, which was conveyed with a top-down approach driven by technological convergence and standardized products and process innovations ("one size fits all solution"), the shift towards a CE is more challenging: it involves more complex system innovations that should necessarily emerge from bottom-up planning. Rather than importing and applying ready solutions, economic agents should actively rethink their business models in co-evolutionary dynamics with the local milieu, given the opportunities offered by the embedded resource-base and actor system relations, as well as considering the environmental hotspots and economic bottlenecks to tackle. For instance, within the olive oil value chain, the circular niche of biogas is a valid and viable option for the most specialized and productive districts with high concentration of by-products, while its applicability is limited in marginal and fragmented areas with more extensive production systems, where the chance to realize economies of scale is lower. Analogously, treated wastewater reuse could become a crucial strategy to alleviate irrigation water scarcity in stressed areas, remaining of minor interest for those with good water resource availability. Moreover, implementing CE approach in the agricultural stage cannot rely merely on technological transfer, but rather entails the acquisition and development of more profound located knowledge (e.g. about ecological processes and biological metabolism).

Thus, basing on the analysis conducted, we highlight that there is not a unique avenue to implement CE, but multiple transition pathways can emerge from many coexisting innovation niches. Each niche comes with a specific socio-technical configuration, and a distinct combination of constraints limiting its uptake, and opportunities to reach and eventually disrupt the socio-technical regime. Different transition mechanisms can occur, depending on the leading niche(s) capable of overcoming constraints and leveraging opportunities, as well as on the socio-economic, cultural, and institutional resources expressed by the territory. To support transition processes, diverse governance approaches and design forms should be applied, depending on the constitutive elements and dynamics of the niche under consideration. Accordingly, differentiated policies and tools can be fashioned, to foster the development of the niche(s) most fitting each sub-regional context.

The present research succeeds in identifying the peculiar configuration (socio-economic, technological, organizational, and environmental features) of the Apulian olive oil production system, and its potentialities and challenges for transitioning into a more circular system. These results represent the knowledge basis on which to build the possible reconfigurations of the system, considering the internal articulation (e.g. the huge territorial diversification and the high level of economic fragmentation) and the urgent external threats represented by the Xylella outbreak for the whole Apulia region. For future research, more effort should be devoted to co-design and/or further developing circular niches with stakeholders and policy makers. In this sense, the gap left after the Xylella outbreak offers a unique opportunity to establish an open-innovation laboratory to boost CET in the Apulian olive oil production system, that could represent a departing point for the whole agri-food sector.

CRediT authorship contribution statement

Sarah Stempfle: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Investigation, Formal analysis, Data curation. **Domenico Carlucci:** Writing – review & editing, Writing – original draft, Visualization, Data curation. **Massimiliano Borrello:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Luigi Cembalo:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Bernardo Corrado de Gennaro:** Writing – review & editing, Writing – original draft, Visualization, Validation, Data curation. **Luigi Roselli:** Writing – review & editing, Writing – original draft, Visualization, Data curation. **Giacomo Giannoccaro:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Funding acquisition, Data curation.

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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.2024.144005.

Data availability

Data will be made available on request.

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