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Research article

Circular bioeconomy for olive oil waste and by-product valorisation: Actors' strategies and conditions in the Mediterranean area

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ABSTRACT

The circular economy and bioeconomy can contribute to transitioning towards more sustainable production and consumption in the olive oil sector. This article is the first to analyse multi-actor strategies and multi-level socio-economic conditions for olive oil waste and by-product valorisation in the Mediterranean area using circular bioeconomy principles. Government policies, the strategies of corporations and farmers and consumers' perceptions are discussed, and various methods are applied, such as desk reviews, case studies and quantitative and qualitative surveys. The findings show strong aspirations for improved sustainability in the olive industry. Furthermore, waste and by-product valorisation strategies foster the creation of innovative practices. However, a common regulatory framework, public financial measures, new circular business models using innovative technologies, multi-actor collaboration and increased consumer awareness of the circular economy and new olive oil waste-based products are necessary for more efficient and sustainable use of olive resources. The policy and management recommendations presented in this study may aid in improving and innovating frameworks and practices for better sustainable management of valuable olive resources.

1. Introduction

The circular economy aims to reduce waste and conserve resources by recycling and reusing products and components and closing resource, material and energy loops (Ellen MacArthur Foundation, 2013). As a novel paradigm to reconcile economic growth with natural resource use, the circular economy emphasises economic and environmental aspects (Geissdoerfer et al., 2017) and addresses various sustainable development goals (Panchal et al., 2021). The European Commission (2012) defined the bioeconomy as converting renewable biological resources into new value-added products, including food, feed, biobased products and bioenergy. The bioeconomy and the circular economy partially overlap (Carus and Dammer, 2018) and have been recently combined into the integrated concept of a sustainable circular bioeconomy (European Commission, 2018). Both aim to contribute to more sustainability by enhancing resource efficiency and material recovery; however, the circular economy addresses novel industrial urban processes for the most efficient utilisation and (re-)valorisation of products and materials, including product-service systems (i.e. selling services instead of products), while the bioeconomy focuses on substituting fossil-based with renewable organic resources and bio-technological innovations (D'Amato et al., 2017; European Environment Agency, 2018; Mak et al., 2020). As highlighted in several recent studies (Jurgilevich et al., 2016; Esposito et al., 2020; Rodias et al., 2021), the circular bioeconomy approach is pertinent for the agrifood system because this sector significantly contributes to greenhouse gas emissions, water and energy use and degradation of natural ecosystems (Velasco-Muñoz et al., 2021). The approach allows for saving precious natural resources and reducing the quantity of waste by converting agrifood waste and by-products into new value-added products (O'Connor et al., 2021; Dutta et al., 2021; Donner et al., 2020), recycling nutrients or changing to more efficient production schemes and

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sustainable consumption habits (Jurgilevich et al., 2016). For measuring the (un)sustainability of food systems, Béné et al. (2019) recently established a set of 27 indicators related to environmental, social, economic and food nutrition and security dimensions; however, transitioning to a sustainable circular bioeconomy in the agrifood domain is challenging. It needs a change at a system level with more sustainable behaviours on the part of all actors (De Vries et al., 2021), new knowledge for developing (bio)technologies and sustainable processes (Abad-Segura et al., 2020) and innovative and broader life cycle methods that can inform policymakers and consumers (Mak et al., 2020). The transition also requires circular business models to propose new biobased products and services that correspond with consumers' expectations (Donner and de Vries, 2021).

Agriculture plays a vital role in Mediterranean countries' socio-economic development, as a source of employment and income and as a cultural heritage. However, increasing agricultural production, in many cases through intensification, is creating negative externalities on society and the environment, such as small-scale farmers' abandonment, biodiversity loss, soil degradation and greenhouse gas emissions (Antonelli et al., 2019). Agriculture is the primary consumer of water in the Mediterranean area, making it imperative to develop intelligent growth schemes and efficiently use all agri-resources (Capone et al., 2016). In addition, the losses and waste from agricultural and food production negatively impact the efficiency of agrifood chains and contribute to nutritional insecurity (Di Terlizzi et al., 2016); a more rational, coherent and efficient agrifood system is needed.

The olive sector constitutes a specific challenge. Across Europe and Africa, nearly 10 million hectares of olive trees are planted, and more than 2.5 million tonnes of olive oil are produced annually (Vilar and Pereira, 2018). From the annual worldwide olive oil production, Spain is the most prolific producer (42%), followed by Italy (17%), Greece (11%), Tunisia, Turkey and Syria (6% in each country) and Morocco (4%) (Khdair and Abu-Rumman, 2020). The olive sector is an essential pillar in the Mediterranean region from socio-economic and cultural perspectives, being part of the healthy Mediterranean Diet; however, olive oil production is resource-intensive, with a high environmental impact related to water and soil pollution and carbon dioxide emissions. The environmental impact mainly originates from the farming phase (pesticide, fertiliser and water use and waste generation) and the oil manufacturing phase (by-products, water and energy use) (Banias et al., 2017). The residual streams are generated by olive pruning (wood, leaves and branches, defined as waste) and olive oil processing (olive pomace and olive mill wastewater, defined as by-products) (Roselló-Soto et al., 2015). The amounts of waste and by-products in the European Union are estimated at 21.4 million tonnes each year, with 9.6 million tonnes/year from the olive mills and 11.8 million tonnes from olive tree pruning (Berbel and Posadillo, 2018). The quantities of water and energy used as input and the generation of wastewater and by-products depend on the plant cultivation type (centuries-old orchard, intensive and super-intensive systems) and the technology used for the extraction (traditional pressing system, continuous two-phase or three-phase centrifugation and de-pitted system) (Cappelletti et al., 2014). Thus, while the two-phase system generates little to no wastewater, the traditional pressing system, the three-phase centrifugation and the continuous de-pitted extraction process produce olive mill wastewater, with 47.80, 51.60 and 53.20 kg of wastewater, respectively, per 100 kg of processed olives (Cappelletti et al., 2014; Doula et al., 2017). Conversely, the centuries-old orchard system requires little water as input and consumes little energy if using a traditional pressing system. At the same time, the other cultivation and extraction methods need considerable amounts of water as input and energy for oil extraction (Cappelletti et al., 2014).

Disposing of olive oil waste and by-products is difficult and costly (Galanakis, 2017). The possible contaminants in olive mill wastewater (phenolic compounds, fatty acids, tannins etc.) are partly phytotoxic and only somewhat biodegradable, making it one of the most polluting effluents in the whole agrifood production system (Souilem et al., 2017). Researchers have proposed various biological, chemical or physical methodologies for olive mill wastewater treatment, which are often inappropriate for scaling up or consume too much time or energy (Zahi et al., 2022). Despite the possibility of using evaporation ponds, wastewater is sometimes still disposed of in the surrounding environment, leading to contamination of soil, plant life or groundwater (Komnitsas and Zaharaki, 2012). Furthermore, managing and transporting wet olive pomace is difficult due to its strong odour emissions and pasty texture (Souilem et al., 2017). Olive oil waste and by-products are traditionally scattered on the soil or used as compost, animal feed or as a heat source; however, there are opportunities to recover valuable compounds, such as specific polyphenols, phenols, proteins, fats, cellulose and lignin, from the waste and by-products (Roselló-Soto et al., 2015). Olive waste and by-products can then be converted into new and higher value-added products, including bioenergy, bio-fertilisers, purified water, biobased materials, food and feed additives, as shown in the biomass value pyramid (Fig. 1). The valorisation is based on circular and bioeconomy principles, such as cascading (extracting valuable biological components before using the remaining biomass for lower added-value products), upcycling (reusing biomass for creating higher added-value products), recycling and recovering (Donner et al., 2020).

The conversion technologies can either be based on thermochemical (via pelleting or pyrolysis, for heat and electricity) or (bio)chemical processes (fractionation, extraction, anaerobic digestion, for bioethanol, biophenols, bio-fertilisers and biogas) or proposing integrated biorefinery concepts that combine several technologies for diversified outputs (Negro et al., 2017; Hernández et al., 2014). Some more recent trends include using olive oil by-products for cement manufacturing (Lila et al., 2020), for innovative functional food (Gullon et al., 2020) or for producing wood glues (Roselló-Soto et al., 2015). The phenolic compounds are particularly appealing for cosmetics and biomedical applications because of their antioxidant, anticancer and anti-inflammatory properties (Barbulova et al., 2015; Otero et al., 2021).

Thus, abundant research exists on chemical or biotechnical treatment options for olive oil waste and by-products (Galanakis, 2017), while social and economic studies, including empirical management practices for waste and by-product valorisation, are scarce and almost non-existent. This is also highlighted by Stempfle et al. (2021: 14) in their recent literature review on circular economy in the olive oil supply chain: *"The results reveal that technological solutions are broadly predominant in the considered body of literature, as the bulk of the works focus on possible technologies or technical practices for recovering and utilizing the waste streams produced within the olive oil supply chain. Only a few studies slightly consider some market aspects …"*. Research is required explicitly on economic, coordination and governance issues (Stempfle et al., 2021). Indeed, only some studies have dealt with political-legal framework conditions (Inglezakis et al., 2012; Doula et al., 2017), circular business models (Donner and Radić, 2021) and the role of sustainability practices in family-owned olive businesses as perceived by consumers (D'Adamo et al., 2019). Additionally, research has covered consumers' acceptance of food obtained from olive by-products (Perito et al., 2020); however, to the best of our knowledge, no socio-economic study exists on circular bioeconomy in the olive oil sector including multi-actor strategies and conditions.

To address this gap in the existing literature, this study's objective is twofold. First, it aims to provide knowledge about the overall state of circular bioeconomy practices and perceptions in the Mediterranean region's olive oil sector. In particular, the research aims to present a more detailed understanding of the key actors in the value chain, their main strategies for valorising olive oil waste and by-products and the most influential related socio-economic conditions. Once the main existing trends for a circular bioeconomy are determined, the second objective is to propose appropriate policy and managerial recommendations to strengthen the circular bioeconomy practices in the olive

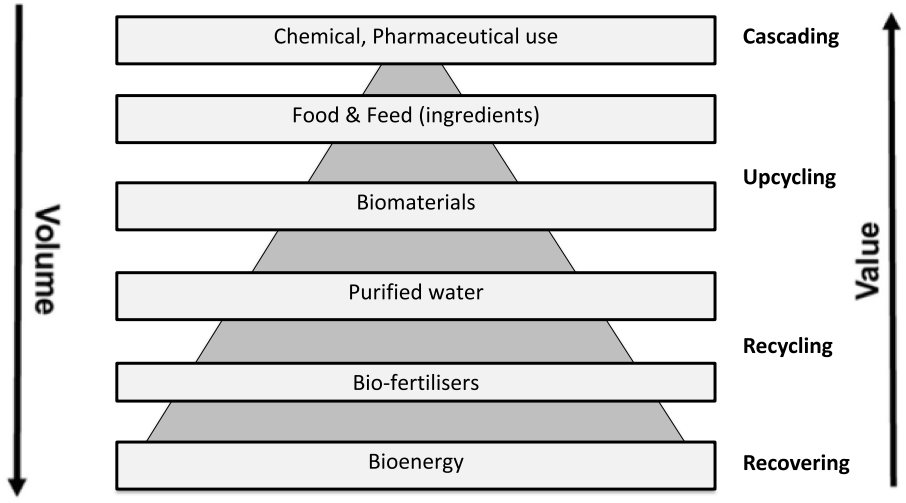

Fig. 1. Biomass valorisation pathways based on circular and bioeconomy principles (modified from Berbel and Posadillo, 2018).

domain. Thus, public policies and businesses, farmers' and consumers' strategies and perceptions are analysed at multiple levels and discussed regarding current main tendencies and actors' interrelations.

2. Methodology

2.1. Overall research approach and methodologies

A qualitative, multi-actor and multi-level approach was chosen to address the aforementioned objectives. The choice of a qualitative approach is adapted to the object of this study insofar as it allows to have depth in the description of the phenomenon (Ridder, 2017) and to better understand its complexity (Moriceau and Soparnot, 2019). Our study can be considered among the interpretivist works in that the generation of knowledge is based on understanding the meaning that the actors give to reality (Thiétart, 2014). Socio-economic research often includes multiple levels (macro, meso and micro) of analysis as the social world deals with interactions between humans and objects (Serpa and Ferreira, 2019). It is particularly appropriate in entrepreneurial research as it enables a comprehensive understanding of contextual influences and causalities, especially between entrepreneurial actors' macro-institutional conditions, behaviour and transformational outcomes (Kim et al., 2016).

In particular, we examined four types of key actors at multiple levels and in various Mediterranean countries (Fig. 2): (i) at a macro-contextual level, environmental policies, including circular bioeconomy and laws for olive oil waste and by-product valorisation, were reviewed in Morocco, Tunisia, France and Spain regarding their current state; (ii) at a meso- and collaborative level, case studies were performed on circular business models within groups of olive oil producers and enterprises; (iii) at a micro-level, individual farmers' strategies, perceptions and needs, as well as consumers' knowledge and perceptions

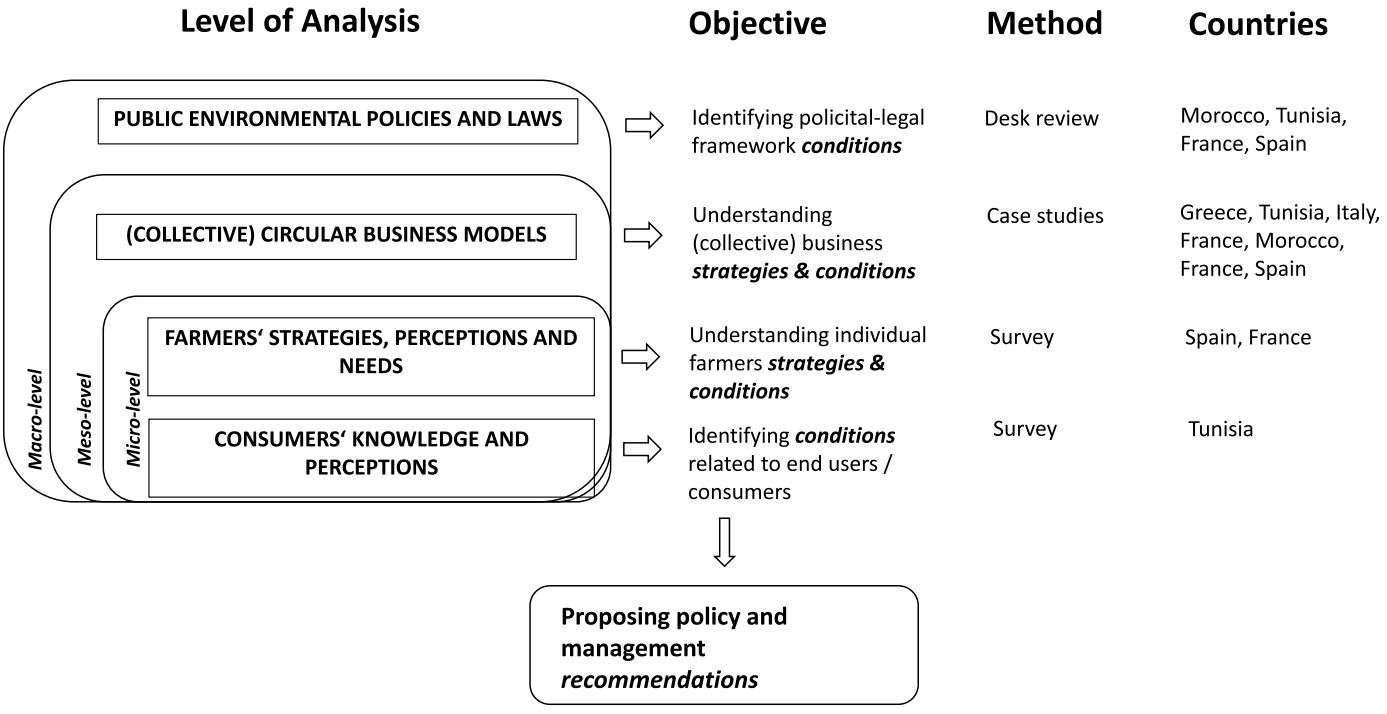

Fig. 2. Multi-actor and multi-level approach (own design).

towards a circular economy in the olive oil sector, were investigated.

Complementary methodologies were applied to analyse the conditions, strategies and perceptions at the different action levels. At the macro-level, desk reviews were done to get insights into the existing policies and legal frameworks that regulate olive oil waste and by-product valorisation. These findings provided input for developing recommendations for more coherent policies in the Mediterranean olive oil sector. At the meso level, ten business case studies were executed to identify current drivers and bottlenecks, including the linkages to the political-legal and market conditions but also internal management and cooperation factors. These insights contributed to the policy and management recommendations for cooperatives and enterprises for a more efficient olive oil waste and by-product valorisation. At a micro level, qualitative and quantitative surveys were done with farmers and consumers to investigate their strategies and perceptions towards circular economy in the olive sector. The results from the farmers interviews and surveys allowed understanding the current farmers' practices and needs, and developing options for policy makers, olive producers and olive oil millers. The insights from the consumer survey contributed to the policy and overall management recommendations.

Surveys and case studies are the appropriate methods for getting qualitative feedbacks and insights in the wide range of stakeholder opinions and complexities; hence, these methods are complementary to quantitative methods. The qualitative insights are in particular relevant for drawing policy and management recommendations at different levels of analysis, where contextual differences exist.

2.2. Data collection and analysis for the four actor groups

First, public environmental policies and laws were analysed (mainly based on an extensive desk review) to identify the most influential (enabling or hindering) political-legal framework conditions for implementing a circular bioeconomy and for the treatment and valorisation of olive oil waste and by-products in the Mediterranean area. This study examined four countries: Morocco, Tunisia, France and Spain. Our primary hypothesis was that valorisation strategies vary according to the actors' legal and organisational choices and level of involvement. The approach was intended to be descriptive and comparative to consider the modes of organisation and development strategies in the four countries. Data was collected from the websites of public and private institutions directly involved in developing the agrifood and olive sector (e.g. ministries of agriculture, environment and development agencies). Books and articles dealing with olive growing and olive oil production in the four countries were also identified and analysed to extract modes of governance from the literature.

The second level of analysis focused on circular business models of groups of farmers or small and medium-sized enterprises. First, existing circular business models were searched for online via google and analysed to understand their overall strategies and waste valorisation pathways, followed by 10 more in-depth business case studies in several Mediterranean countries (three cases in Greece; two in Tunisia; two in Italy and one each in France, Morocco and Spain, cf. Table 2 below) to unfold key enabling or hindering factors. These cases were selected based on the diversity of (i) countries and their contexts (ii) types of initiatives (e.g. family business vs. cooperative, small vs. large scale), and (iii) business model elements, i.e. the diversity of resources used and value propositions. The data available online (websites, videos and articles) was first compiled for each case. Later, semi-structured interviews were conducted with the enterprises and cooperatives managers, mainly via online meeting tools due to the coronavirus travel restrictions in 2020–2021. On-site visits were still possible for the two cases in Tunisia, as they were conducted before the pandemic started. Donner et al.'s (2020) semi-structured interview guide for circular business model assessment was adapted for the olive sector and Mediterranean context (cf. Supplementary material 1). The interview guide included questions about political-legal and market conditions; business origin; objectives and development and technological, organisational, marketing and financial aspects. The interviews were conducted in French, English, Spanish and Italian. To increase the validity of the results, the primary interview data was triangulated with the secondary data collected online. Content analysis was used to treat the data, which consists of an analytical data interpretation and is used to make *"replicable and valid inferences from texts"* (Krippendorff, 2004: 18). Contents regarding business model elements, marketing strategies, success and risk factors could be identified.

Two surveys were done in Spain and France concerning individual farmers' strategies and conditions. In the Terres de Ponent area in Catalunya, Spain, 59 small olive farms with less than 300 ha (ha) of agricultural land and less than 10 ha dedicated to olive orchards were studied. To investigate farmers' perceptions towards more circularity, the olive oil by-product valorisation practices were addressed, including resource management, waste treatment and the farm's viability (for the questionnaire used cf. Supplementary material 2). Semi-structured, in-person interviews lasted between 1 and 1.5 h. The data analysis applied descriptive statistics to characterise the sample, understand what type of by-product management and valorisation strategies are present in the field and determine the degree of implementation within the sample. Furthermore, Nvivo software was used to analyse and examine the farmers' viewpoints. In France, with the aid of France Olive, the interprofessional olive association, an online survey was conducted on 37 olive farmers, millers and olive oil cooperatives to learn about their current practices and perceptions of waste valorisation opportunities and future needs to transition towards circular business models. Questions included the main characteristics of the businesses, their olive plantation methods, olive oil production and commercialisation, valorisation paths, bottlenecks and future needs for olive oil waste and by-product valorisation (cf. Supplementary material 3). Data were treated using descriptive statistics and qualitative thematic analysis.

For understanding conditions related to the end-users, consumers' knowledge and perceptions of the principles of circular economy as well as motives and barriers for the transition to the circular economy in the olive oil sector were explored. The study was based on data from an online survey conducted from May to July 2021 on a sample of 318 regular adult olive oil consumers in Tunisia. The internet research was not random, as participants were reached via specific channels (Coderoni and Perito, 2020). The survey was executed using a questionnaire structured in seven parts regarding 1) purchasing habits of olive oil; 2) knowledge and attitude towards the geographical origin of olive oil; 3) knowledge and attitude towards local olive oil; 4) consumption habits of olive oil; 5) knowledge and uses of olive oil by-products and waste; 6) knowledge and attitudes consumer towards the circular economy generally and the circular economy of olive oil more precisely; 7) socio-demographic questions (cf. Supplementary material 4). The questionnaire was tested utilizing a pilot survey with 20 olive oil consumers. This pre-test identified issues that could be misinterpreted by consumers or that might require too much effort to answer.

An exploratory analysis of the consumers' knowledge and perceptions of the circular economy and the main benefits and barriers to implementing a circular economy model in the olive oil sector was performed. Subsequently, to identify issues associated with the circular economy, consumers were asked to express their agreement or disagreement on a scale from 1 (strongly disagree) to 5 (completely agree) concerning circular economy-related statements. The ratings for each aspect of the circular economy were summarised using principal components factor analysis (Varimax rotation), which reduces many variables (factors) into a smaller number. It also identifies underlying dimensions of measured factors and latent constructs. Since we had no expectations of the number and the nature of the factors, we used an exploratory factor analysis instead of the confirmatory analysis suggested by Taherdoost et al. (2014). All data analyses were conducted with the SPSS Version 24.0 programme.

3. Results

3.1. Public environmental policies and laws for olive waste and by-product treatment

The Moroccan public authorities are aware of the importance of the environment and have undertaken regulatory and institutional approaches to tackle the challenges of climate change and environmental protection (Yatribi et al., 2019). Although the circular economy concept is relatively new in Morocco, these approaches consider its principles, especially regarding waste management and recovery (Diaco et al., 2020). Still, different policy frameworks and environmental regulations exist. For example, the *National Strategy for Sustainable Development 2030*, introduced in 2019, includes circular economy-related principles for water, energy, forest, agriculture, cities, transport and waste. For the agricultural sector, the *Green Morocco Plan* was launched in 2008, fostering locally diversified development and sustainable foreign investment (Diaco et al., 2020). Additional actions have been introduced to protect the environment against pollution and degradation, such as Law No.11.03 (Loi n° 11-03 relative à la protection et à la mise en valeur de l'environnement, 2003) and No.99–12 (Charte Nationale de l'Environnement et du Développement Durable, 2014). Regarding waste management and disposal, Law No.28–00 (Loi n° 28-00 relative à la gestion des déchets et à leur élimination, 2006) aims to reduce and recover waste. It applies to general waste, household and similar, inert, industrial, hospital and hazardous waste, covering by-products from the olive oil industry. There are also laws for advancing renewable energy use, e.g. No.13-091 (Loi n° 13-09 relative aux énergies renouvelables, 2010), for opening the competition of renewable electricity production and giving access to the national electricity grids.

Due to its high environmental vulnerability, especially regarding limited water resources, Tunisia has early taken initiatives for environmental and resource protection, e.g. by ratifying the Convention on Climate Change by the United Nations in 1992 (Fersi et al., 2021). It was also one of the first African countries to develop plants for wastewater treatment and controlled landfills (Fersi et al., 2021), and several laws regulate the treatment of olive oil waste. Olive mill wastewater is legally considered industrial wastewater, and its disposal is regulated by Norm NT106-02 (relative aux rejets d'effluents dans le milieu hydrique, 1989), establishing concentration limits for several parameters for the wastewater to be rejected in the environment or for use in treatment plants. Modern purification or disposal processes do not treat olive mill wastewater on a large scale; it is primarily evaporated in storage tanks. This process makes it possible, after a certain period, to obtain an organic material suitable for use as fertiliser; however, this approach is hindered by a thin film of oil on the surface of the basins that impedes the evaporation.

It should be noted that both Morocco and Tunisia participate in the SwitchMed Program[1] funded by the European Union. This programme enables a circular economy transition by providing a regional action framework and supporting policymakers and innovative enterprises from the southern Mediterranean region.

The European Commission launched its first Circular Economy Action Plan in 2015 (European Commission, 2015) to accelerate the transition by closing product lifecycle loops through recycling and reuse. The action plan was updated in 2020 (European Commission, 2020), in line with the European Green Deal. The European Bioeconomy Strategy was launched in 2012 and extended in 2018 (European Commission, 2018), integrating sustainable and circular principles. Its objective is to combine industries' sustainable usage of renewable resources with food security and environmental protection. Circular and bioeconomy strategies also exist at national levels. In France, a bioeconomy action plan was implemented in 2018 (Ministère de l'Agriculture et de la Souveraineté Alimentaire, 2018) followed by a plan for the circular economy in 2021 (Ministère de l'Économie, des Finances et de la Souveraineté Industrielle et Economique, 2021). In Spain, a bioeconomy strategy has existed since 2015 (Ministerio de Economia et Competitividad, 2015) and a circular economy strategy since 2021 (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021). Concerning olive oil waste and by-product treatment, the European Union has not yet developed any common legislation (Doula et al., 2017). Individual national regulations, especially for the olive mill wastewater, exist in diverse European countries; however, the regulations are not always the same and do not always concern all types of olive oil waste or by-products. For example, in France, the treatment of olive oil by-products (wastewater and olive pomace) is defined by the Environmental Code and the Classified Installations for the Protection of the Environment (France Olive, no date); however, no regulation exists for olive tree pruning biomass (leaves and branches), and burning is still allowed. In Spain, a Ministerial Decree for waste disposal was issued in 2002, according to the European Waste List (MAM 304/2002); however, olive mill wastewater and pomace were not considered as dangerous waste but as by-products that could be further valorised (Doula et al., 2017). The Decree April 2011 of the Andalusian Regional Government allows wastewater use as agricultural soil amendment, with a limit of 50 m3/ha/year (Doula et al., 2017).

The public environmental policies and laws for olive oil by-product treatment are summarised in Table 1, highlighting that policies in the Mediterranean region are increasingly oriented towards more ecologically-friendly management practices; the circular economy and bioeconomy have especially gained importance.

3.2. Circular business models

A previous review of initiatives (Donner and Radić, 2021) illustrated that some innovative business models in the Mediterranean specialise in olive oil waste valorisation; however, the overall olive biomass potential seems to be under-valorised, and relatively low adding-value strategies (bioenergy or fertilisers) are applied. Of the 10 business cases studied in-depth (Radić and Donner, 2021), eight mainly produce olive oil and valorise waste and by-products, and two only valorise by-products (cases 1 and 10 in Table 2). Value propositions are bioenergy (heat and electricity), cosmetics and soaps, ingredients for animal feed or materials for the construction industry and an innovative technological solution for olive oil production using less water.

Concerning the key enabling or hindering factors of circular business models, the results indicate that internal and external factors exist.

The principal internal success factor is an environmental and agronomic concern, which is the awareness of the importance of care for the environment, especially in water, scarcity and toxicity of wastewater. Enterprise managers engaging in the circular economy are aware that they need to adopt more sustainable practices for the long-term continuation of their activity. Another critical enabling factor is knowledge, referring to the educational level and know-how of modern technologies, as well as knowledge of marketing strategies. Furthermore, well-organised logistics and the availability of local agricultural resources are critical factors. Logistics includes collecting waste and by-products from the olive plantations and mills and the logistics for bringing raw materials or final products to markets. Here there is a need for a synchronised and well-organised waste collection from many small mills often spread within a territory. The proximity between the waste generation and waste valorisation sites is advantageous.

Concerning the external enabling factors, obtaining subsidies and being involved in development projects is essential. For example, one enterprise was participating in the Mediterranean circular economy development project SwitchMed and the Ministry of Environment projects. Both supported the development of activities, provided a potential pool of new resources and collaborations and could act as a promotional tool. Furthermore, the requirements of civil society and consumers

[1] https://switchmed.eu/.

Table 1
Summary of the environmental policies and olive by-product treatment laws in the four countries.

	Morocco	Tunisia	France	Spain
Public environmental policies	• National Strategy for Sustainable Development 2030 (<2019) • Green Morocco Plan (<2008) • SwitchMed Circular Economy Program (<2013)	• Ratification of the Convention on Climate Change by the United Nations (<1992) • SwitchMed Circular Economy Program (<2013)	• Bioeconomy action plan (<2018) • Law for transition to a circular economy (<2021)	• Bioeconomy strategy (<2015) • Circular economy strategy (<2021)
Laws for olive oil by-product treatment	• Law No.28–00 (<2006) to reduce and recover (industrial) waste	• Norm NT106-02 (<1989) for industrial wastewater	• Environmental Code (<2000), Classified installations for the protection of the environment, including olive oil by-products	• Decree April 2011 of the Andalusian Government for wastewater use as soil amendment

Table 2
Overview of the 10 cases studied.

Case	Country	Type of enterprise	Main activities and value propositions
1	Morocco	Private enterprise	Production of energy (heat, electricity)
2	Tunisia	Family enterprise	Refinery for production of olive pomace oil, biodiesel, biomass
3	Tunisia	Private enterprise	Production of extra virgin olive oil, give waste to animal farmers for feed and sale of olive pomace to oil refinery
4	Greece	Cooperative	Olive growing, production of extra virgin olive oil, animal husbandry
5	Greece	Shareholding private company	Production of extra virgin olive oil, give waste to animal farmers for feed and sale of olive pomace to oil refinery
6	Greece	Cooperative	Production of extra virgin olive oil, pomace oil, soap, biomass
7	Spain	Cooperative	Production of refined pomace oil
8	Italy	Cooperative	Olive growing, production of olive oil and wine production, provide biomass for heating in local public buildings
9	Italy	Family enterprise	Production of olive oil extraction unit for mills, technological solution for olive oil production using less water
10	France	Union of cooperatives	Valorisation of agricultural waste (issued from wine, olive and fruit production) for diverse products and applications

matter greatly; in one case, demand for heating with olive biomass came from a food industry where more sustainable practices were introduced in the overall management after consumers claimed a cleaner and more sustainable production. Legal obligations, particularly those related to wastewater treatment or regional standards regarding the preservation of landscapes, are another reason enterprises should adopt circular economy principles.

The most significant risk factors for successfully implementing circular business models are external financial support, high costs for investment and challenges related to partnerships needed for research and development activities. Although the sector urgently needs subsidies to invest in waste valorising activities and innovative technologies, most enterprises lack specific support.

3.3. Farmers' strategies, perceptions and needs

The key results from the research conducted in Catalonia (Manuel-i-Martin et al., 2021) indicate that small olive oil farmers broadly apply circular economy strategies of olive farming or olive oil making; 49 out of the 59 (83%) interviewed farmers have adopted some valorisation strategy. The most prevalent method of valorising olive tree pruning biomass (branches, leaves) is to shred and recirculate it within the farm as organic matter (71%) rather than the traditional burning approach. Another strategy is to sell raw olive pomace to an olive oil refinery (37%). Furthermore, the use of olive stones for bioenergy production (14%) and the conversion of olive pomace into fertiliser (10%) was present in the sample but less popular. Exceptionally, pruning biomass is used as animal feed or olive mill wastewater sold for cosmetic production (5%). The current valorisation paths of Catalonian farmers are illustrated in Fig. 3.

Analysing the farmers' perceptions, however, shows that circular economy approaches are yet not well established. The different strategies from the sample respond to the need to manage specific by-products and waste generated during olive and olive oil production rather than being part of a broader circular business model approach. Similarly, the presence or absence of olive oil manufacturing determines the by-products olive farmers need to manage; pruning biomass is common among all olive growers, while the more complex olive pomace is unique to olive oil producers.

Thus, farmers' most common by-product valorisation strategies in Catalonia are low-value uses, both on the farm and in olive oil mills. The most usual strategy is selling olive pomace to oil refineries as raw material. The driver for this practice is not to obtain an extra income but to solve a problem: necessarily discarding olive pomace. The conversion of olive pomace into valuable products takes place outside the control of small olive farmers, who, in the region of Terres de Ponent, only have one buyer available and consider the price of olive pomace too low. Accordingly, small olive farmers more positively perceive valorisation strategies that involve recirculating by-products within their farms, such as using olive pomace as fertiliser or extracting olive stones; however, these recirculation strategies are less usual, as they require investments like machinery and infrastructure.

In France, the 37 survey respondents (farmers, millers and co-operatives) valorised pruning biomass (38.2%), olive pomace (29.4%), olive pits (8.8%) and wastewater (5.9%). Regarding the valorisation pathways, none of the respondents implemented water purification, refined the olive pomace or used waste and by-products to produce electricity (Fig. 4). Currently, heating briquettes are also not produced; however, 24.3% use olive pits for heating. Spreading waste in fields is a technique applied by13.5%, and 11% use waste for composting or as fertiliser. An outdated practice of burning the branches and other pruning residues is done by 5.4%, and 24.3% produce soap. Of those who produce soap, 50% use olive oil with elevated acidity and 40% use extra virgin olive oil.

When asked about the requirements for implementing circular business models in the olive oil sector, the following answers were given, highlighting the need for public-private collaboration and technical and financial support (Table 3).

3.4. Consumers' knowledge and perceptions

Results from the consumer survey (Erraach et al., 2021) point out that Tunisian consumers currently have relatively low knowledge and a general understanding of the circular economy: 47% of respondents had never heard about the circular economy, 24.2% had just heard of it and only 28.8% knew what it was. The respondents' most reported features

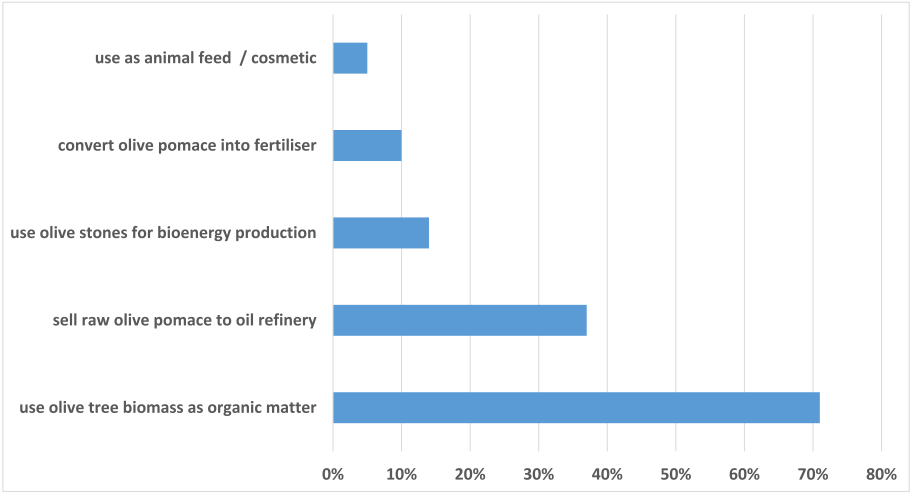

Fig. 3. Current valorisation of olive waste and by-products by Catalonian farmers, millers and cooperatives (59 respondents).

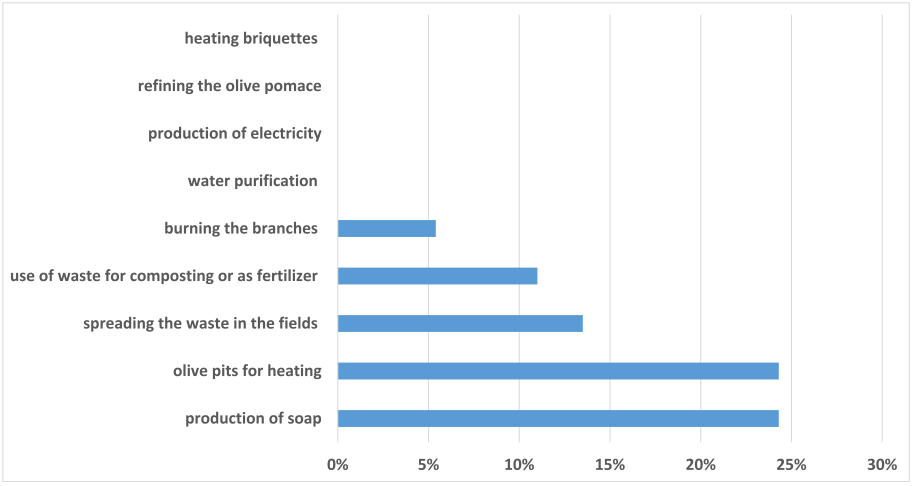

Fig. 4. Current valorisation of olive waste and by-products by French farmers, millers and cooperatives (37 respondents).

Table 3
Farmers' requirements for implementing circular business models in the olive oil sector.

Needs for olive oil waste and by-product valorisation, as expressed by French farmers/ cooperatives	
Category	Quotation
Public-private collaboration	*An efficient and adapted collection for treatment of the mill waste by a company, a community, an association or other … Legislation much less constraining for the Mills.* *In our mill located in the heart of the village, the two main problems are the lack of storage space and the lack of electrical power.*
Technologies	*Management of the by-products by crushing. What to do with the pomace and wastewater? Biogas production? Food for the cattle? The whole profession is looking for solutions.* *To incite or even oblige the mills to separate the pomace and the wastewater (3-phase mill). To be able to use the dry pomace, which is the only organic matter that can be used as fertiliser.*
Human and/or financial support	*Volunteers, voluntary work.* *For the valorisation of the olives, we would need to be able to communicate with specialists who know and can give us their opinion.* *I am interested in advice and support for obtaining briquettes or pellets for heating.* *Technical and financial support.*

included 'sustainability of production', 'reduce environmental impact', 'recycling' and 'waste management'.

A factor analysis was used to explore how consumers perceive the circular economy concept, investigating the underlying dimensions (factors) of the circular economy as perceived by consumers (Table 4). Respondents were asked to indicate their degree of disagreement or agreement on a 5-point Likert scale, including sixteen statements related to the potential benefits of a transition to a circular economy. The Kaiser–Meyer–Olkin (KMO) (Kaiser, 1970) was used to assess the sampling adequacy. The result for the KMO test was 0.95, considered a suitable value by Hair et al. (1995). Bartlett's Test of Sphericity (Bartlett, 1950) confirms that the item correlation matrix is not an identity matrix. Therefore, we can move to exploratory factor analysis interpretation.

The factor analysis revealed two dimensions, explaining 75.62% of the total variance of responses. The first dimension, 'environmental and economic benefits', was defined by attributes linked to the protection of the environment, the preservation of natural resources, the reduction of pollution, the creation of new jobs and enterprises and benefits for the country's economy. The second dimension, 'benefits for consumers and producers', included attributes principally related to production efficiency, reduction of production costs and increased producers' profitability. This factor also focused on what consumers perceive as the benefits of the transition to the circular economy, such as new products, healthy food and affordable prices.

Table 4
Consumer perception of circular economy: factor-analysis results.

Component matrix after rotation[a]		
The transition to the circular economy	Component	
	1	2
Promotes environmental protection	0.904	0.288
Generates benefits for the natural environment	0.887	0.315
Ensures the preservation of natural resources	0.858	0.329
Reduces pollution	0.837	0.317
Generates benefits for the national economy	0.772	0.392
Allows the reuse and recycling of waste	0.892	0.293
Guarantees more efficient production	0.500	0.706
Reduces production costs	0.323	0.745
Increases the profitability of producers	0.250	0.674
Contributes to the creation of new jobs	0.681	0.465
Allows the creation of new businesses	0.463	0.711
Generates benefits for society	0.442	0.743
The transition to the circular economy offers consumers new products	0.577	0.660
Helps meet the needs of price-conscious consumers	0.273	0.810
Helps meet consumer demand for healthy food	0.288	0.791

Measure of sampling adequacy of Kaiser–Meyer–Olkin: 0.951, Total explained variance = 75.62%.
[a] The rotation converged in three iterations.

At the same time, 36% of the respondents associated olive oil production with a negative environmental impact, mainly due to water consumption (for irrigation and processing) and waste management, especially olive mill wastewater.

Respondents were also asked about the main barriers to the transition to a circular economy in the olive oil sector in Tunisia; numerous elements, such as a lack of public awareness as the most important, were named by 79%. Next, they stated a lack of financial support (67%), followed by a lack of legislation (59.5%) as obstacles to developing a circular economy in the Tunisian olive oil sector.

The participants provided several reasons why a circular economy should be developed in the olive oil sector, and 80% indicated issues linked to environmental protection. Furthermore, about half of the respondents indicated that a circular economy should be implemented to reduce costs in the sector.

Consumers were also asked about their perceptions of olive oil, including circular economy principles, compared to conventionally produced olive oil. Most (57%) perceive olive oil issued from a circular economy as less harmful to the environment, and 43% perceive it as more sustainable, including economic, social and environmental dimensions. They also felt that olive oil from a circular economy is produced following traditional know-how (23%) and is of superior quality (20%).

4. Discussion and recommendations

The analysis of the four different actors' groups of the olive oil value chain demonstrates the following general tendencies, enablers and bottlenecks for implementing circular bioeconomy practices in the Mediterranean olive oil sector.

First, in the four studied countries, some policies towards a circular economy, laws for the protection of the environment and (olive) by-product management exist; however, a common legal framework for olive by-product management does not exist, even not at the European level (Batuecas et al., 2019). Additionally, the treatment of olive pruning waste (branches, leaves) is not always regulated, with the consequence that this valuable biomass is often still burned. Furthermore, the stakeholders' interviews and surveys indicated a lack of real political incentives and financial resources to actively support the valorisation of olive oil waste and by-products.

Second, the main internal enablers for circular business models include environmental concern, knowledge about waste valorising technologies and markets, long-term presence in the sector and logistics. External enablers include a circular economy anchored in the local policy agenda, legal waste treatment obligations and consumers' requirements. Two risk factors are challenging partnerships for research and development and a lack of public financial support, especially for investments in technology. Despite the mainstream policy narrative for a circular bioeconomy, there is often still a lack of concrete governmental support for enterprises involved in olive oil waste and by-product valorisation activities, as the majority of the examples studied did not have access to subsidies. The importance of valorisation is recognised but rarely or insufficiently supported in practice.

Third, the farmers' study in Catalonia indicates that most small olive farmers follow some circular economy strategy; however, they are primarily motivated by eliminating their waste problem rather than participating in cohesive circular production systems to generate additional income. Farmers in France declared that more collaboration and technical and financial support would be needed to put value-adding practices in place. Currently, most farmers' by-product valorisation strategies in both regions are low-value uses (heat, spreading in the field, fertiliser, sales of raw pomace), on the farm and in olive oil mills.

Fourth, in the Tunisian olive sector, findings indicate that consumers' knowledge and perceptions of the circular economy are minimal. This result is consistent with the findings of Costa and Donner (2019), indicating that most of the participants in France (more than 80%) had never heard about the circular economy before; conversely, Anlas (2019), who concluded that Turkish people have some awareness (64%) of the concept of the circular economy. It is interesting to highlight that even though knowledge of the circular economy was poor among Tunisian consumers, they perceive it positively. Their perceptions can be summarised in two main dimensions: environmental and economic benefits and consumers' and producers' benefits. Consumers expressed high expectations for environmental and economic benefits when discussing reasons for a transition to a circular economy in the Tunisian olive oil sector. They highlighted a lack of public awareness and financial support as significant barriers for the olive oil sector to transition to a circular economy.

These insights suggest that the different actors' environmental awareness and expectations regarding more sustainability in the Mediterranean olive oil sector are high, and policymakers, businesses and farmers are already making efforts. Still, the transition towards a circular bioeconomy in practice is far from being sufficiently advanced and remains challenging. The results also illustrate the need for more interactions, coordination and collaboration. Notably, as the main actors in putting sustainability into practice, farmers and businesses need to work together for shared value creation based on olive oil waste and by-products. These two actor groups also depend on public laws and subsidies for waste conversion technologies and need to fulfil the sustainability requirements of consumers. Fig. 5 demonstrates the interrelations of the actor groups and leads to the policy and managerial recommendations.

Hence, our mixed methodological approaches (desk reviews, case studies and surveys) selected for the three different levels of analysis allows drawing recommendations for each level of analysis. Even more, it allows interlinking recommendations at the different levels of analysis. The latter is of key importance in our systemic approach to unravel the complexity of olive waste and by-product valorisation pathways.

Based on the insights regarding the prominent trends among the key value chain actors' groups and the bottlenecks and needs for olive oil waste and by-product valorisation, we propose the following detailed recommendations for policymakers and managers of olive farms, mills, cooperatives and olive oil waste valorising businesses.

4.1. For policymakers

- In general, to develop a common regulatory basis at a Mediterranean level and for all olive oil waste and by-products, based on existing

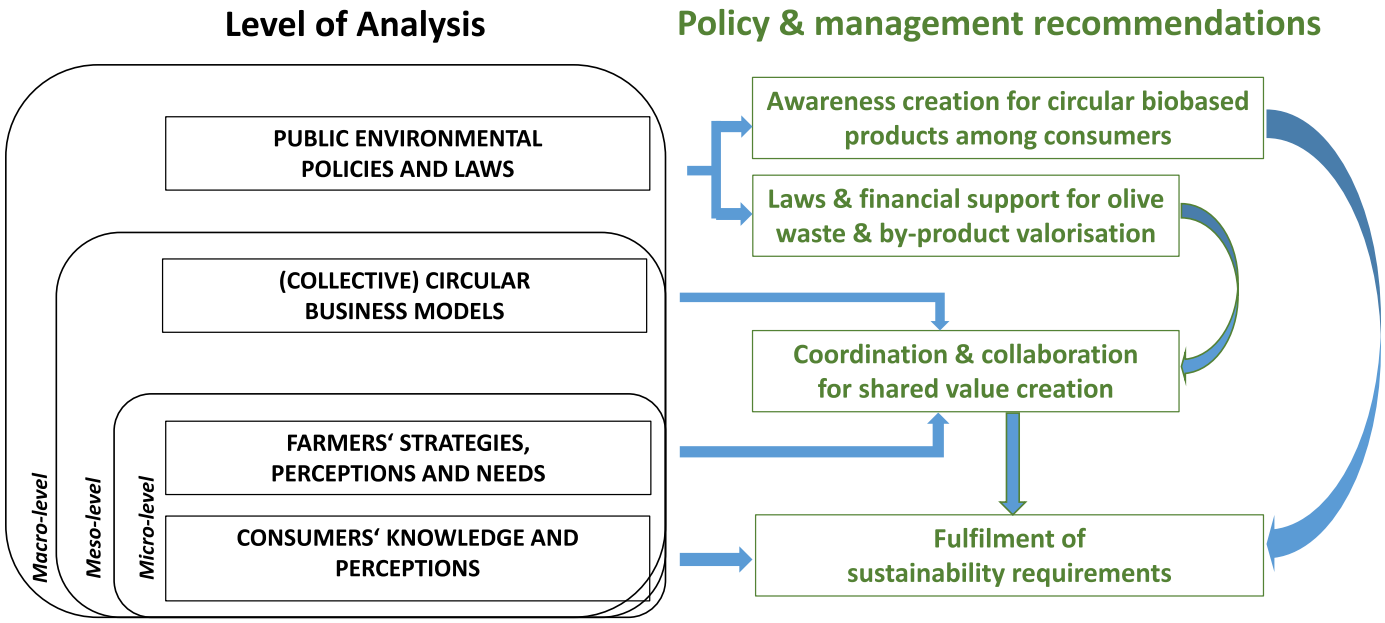

Fig. 5. Interrelations of the different actor groups studied (own design).

national laws, regulations and recommendations or best practice guides. This could be achieved by the International Olive Oil Council, the leading institution in the olive sector, whose mission is also to harmonise national and international regulations.

- Specific policies are recommended to assist olive oil farmers and cooperatives in incorporating alternative valorisation strategies for olive pomace rather than selling it at a low price to olive oil refineries. Such policies could connect olive oil cooperatives with research projects or businesses dedicated to manufacturing high-value products out of olive oil waste, so the value created could be more directly shared by the farmers at the start of the production chain.
- The extraction of olive stones to be used as bioenergy is a growing strategy among small olive oil producers, and policies that offer financial support to invest in the necessary infrastructure and inform of the benefits of the strategy could further encourage implementation among small olive and olive oil producers.
- In a broader scope, policies that support the return of extensive livestock farming in olive-producing areas would benefit circular synergies between olive farming and livestock farming, where olive tree pruning biomass could be valorised as on-farm animal feed.
- Consumer knowledge of the circular economy is still generally low, highlighting the importance of communicating marketing plans for circular projects. Such plans can expose producers' benefits through circular economy products, including olive oil, and raise awareness among consumers of the crucial importance in reducing environmental problems caused by the olive oil industry.

For business managers, the recommendations are addressed to olive producers (farmers), olive oil millers, cooperatives and enterprises specialising in olive oil waste valorisation:

- Olive producers can include recirculation of waste and by-products strategies, such as valorising olive tree pruning biomass directly in the olive plantation for compost or (in moderation) as animal feed. As an upcycling opportunity, farmers could collect leaves and dry them for herbal infusions (highly appreciated as an antioxidant).
- Olive oil millers can consider a change for more advanced technological solutions for mills (three-phase) with fewer wastewater or olive cake amounts. Furthermore, applying a technic for olive kernel separation and valorisation of the olive kernel as a heating component. Olive pomace can be used to extract olive pomace oil, which can be offered to food industry customers; traditional soap is a further possibility for upscaling olive pomace oil.
- There are two sets of recommendations for agricultural cooperatives: organisational and technological. At the organisational level, developing a professional management team, ideally composed of experienced professionals and young experts with adequate knowledge and mindset for implementing new technologies, would be beneficial. At the technological level, agricultural cooperatives could implement cascading principles with full utilisation of olive resources.
- Finally, enterprises specialising in olive oil waste valorisation (often the innovators and the change factors in the sector) are mainly recommended to develop a partnership with research institutes to fine-tune their innovative ideas or upscaling their technological solutions. Such a collaboration (between a private enterprise and public research institutes or universities) is highly valued among financial institutions that serve as donors for innovation projects. It is also crucial to raise consumer awareness and information about circular economy principles before the launch of products and to meet consumers' requirements for sustainability. This is also suggested by Whitehair et al. (2013), who insist on educating people for leading their behaviours on more sustainable paths.

Table 5 summarises the central policy and management recommendations for policymakers and managers of olive farms, mills, cooperatives and olive oil waste valorising businesses.

5. Conclusion

This article contributed to an overall understanding of various key actors' strategies in the olive oil value chain and enabling or hindering socio-economic conditions for valorising olive oil waste and by-products via circular economy approaches in the Mediterranean area. Overall, it has confirmed previous research results (Donner et al., 2021; Velasco-Muñoz et al., 2021) in that the transition to a sustainable circular bioeconomy remains complex and challenging, calling for a systemic approach including various actors and technological, organisational and social innovations. Specifically, the findings indicate that actors' aspirations for improved industry sustainability are currently strong, and their waste and by-product valorisation strategies foster the creation of

Table 5
Policy and management recommendations.

Actor group	Recommendation
Policymakers	- Develop a common regulatory basis for all olive oil waste and by-products at a Mediterranean level. - Assist olive oil cooperatives in incorporating alternative adding-value valorisation strategies for olive pomace than selling it to olive oil refineries. - Offer financial support to invest in the necessary infrastructure for olive stone extraction for bioenergy use. - Support the return of extensive livestock farming in olive-producing areas would encourage circular synergies. - Raise consumer awareness of circular economy and environmental problems in the olive sector.
Olive producers (farmers)	- Valorise agricultural waste directly in the olive plantation (branches, leaves) as compost or animal feed. - Upcycling opportunity by drying leaves for herbal infusions. - Consult experts for advice and support.
Olive oil millers	- Use advanced technological solutions for mills (three-phase) with fewer wastewater or olive cake amounts. - Apply a technic for olive kernel separation/ valorisation of the olive kernel as a heating component. - Use olive pomace oil for the food industry or traditional soaps.
Olive and olive oil cooperatives	- Build a professional management team with adequate knowledge and mindset for implementing new technologies. - Implement cascading for full utilisation of olive resources locally. - Create partnerships between olive growers and animal herders.
Enterprises specialising in olive oil waste valorisation	- Develop partnerships with research institutes for fine-tuning innovative ideas and upscaling technological solutions. - Build public-private partnerships, valued among financial institutions serving as donors for innovation projects. - Develop a marketing (communication) strategy.

innovative practices. Still, several factors are required for a more efficient and sustainable usage regarding economic, environmental, social, food and nutrition security dimensions of olive resources. These include a common regulatory basis, facilitating public financial measures, new circular business models using innovative technologies, collaboration among farmers, businesses and research for shared value creation and increased consumers' awareness of circular economy and new olive oil waste-based products. Engaging actors across various levels of action in continuous exchange and cooperation is essential to co-create value out of olive oil waste and by-products. In the Mediterranean region, the proposed targeted recommendations might help improve and innovate policies and practices for sustainable olive resource management. Further research should focus on the collaboration among different actors and the marketing and communication strategies towards consumers.

Credit author statement

All authors contributed to the conception of the study, the acquisition of data, the analysis of the data, the revision of the manuscript, and approved the final version of the manuscript. M.D. drafted the 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.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2022.115836.

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