CircOlive

Developing skills for introducing circular business models and digital technologies in olive oil sector

D2.2 Comparative Research Report on current situation in the olive oil sector

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Comparative Research Report on current situation in the olive oil sector

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1
Executive Summary

1. Executive Summary

Olive oil production is an important agricultural activity in the world. By-products and waste from the olive oil production sector represent significant environmental challenges, but also offer opportunities for innovation and sustainability. By adopting integrated waste management strategies and investing in research and development, we can improve the sustainability of the olive oil sector and contribute to the circular economy.

This report summarizes the current circular practices and technological gaps in the olive sector in Spain, Italy, Greece, Portugal and Croatia and analyzes the potential of developing a program for vocational education and training on circular business skills in the olive sector in order to adapt the provision of vocational education and training to the emerging needs of circular business skills.

The report is part of Work Package 2 (Identification of olive sector circular needs and emerging skills and/or professions for transition of the olive oil sector to a circular economy in the 5 countries) of the CIRCOLIVE project (Developing skills for introducing circular business models and digital technologies in the olive oil sector) and represents deliverable D2.2 (Comparative Research Report on the current situation in the olive oil sector).

1.1 Background and Purpose

The areas under olive groves in the world are constantly increasing. During olive production and the processing of olive fruits into olive oil, large amounts of by-products and waste are created, such as pruning residues, olive pits, olive pomace and wastewater, which should be valorized by circular business practices. Despite its economic importance, the olive oil sector faces significant challenges in managing its waste. In many production regions, the current waste management practices include basic methods that do not fully mitigate the environmental impact.

General strategies for the adoption of environmentally friendly practices, prevention measures, intensive controls of the production processes and provision of technical assistance and theoretical knowledge to every stakeholder of the sector, is the basic assumption for the transition of the olive oil industry to a circular economy model.

With the aim of reducing the negative impact of the mentioned by-products on the environment, the CIRCOLIVE project will support the EU's transition to a circular economy by improving/strengthening circular business skills in the olive oil sector in Spain, Italy, Greece, Portugal and Croatia, in order to promote the adoption of circular business models for the valorization of waste and by-products from the entire olive sector. The project will encourage the adaptation of the provision of vocational education and training to the emerging needs for circular business skills in the olive sector by developing transnational curricula.

This Comparative Research Report summarizes the current state and needs of the olive oil sector in five European countries (Spain, Italy, Greece, Portugal and Croatia).

1.2. Key Findings

In this report, the research results of primary and secondary sources of data on the state of the circular economy in the olive sector and olive oil production in Spain, Italy, Greece, Portugal and Croatia are presented. Primary sources included field data collection on a planned sample of respondents through a survey and interviews with relevant stakeholders in the olive sector, olive oil production and education providers. Secondary data included the analysis of available literature related to this topic. Data was collected on the numerical indicators of olive production, the technologies used in the olive grove, the handling of residues after pruning in the olive grove, the methods and capacity of processing olives into olive oil, the quantities and handling of by-products/waste after olive processing, and the prevalent circular economy practices in the olive growing sector and oil industry as well as potential institutions that could provide vocational education and training in the area of the circular economy. The obtained research results provide an insight into the current state of the circular economy and provide an overview of the opportunities, strengths, weaknesses and threats of the implementation of the circular economy in the olive oil sector.

While showing a strong commitment to managing by-products sustainably, olive oil sector faces several barriers to fully integrating circular economy practices. These include a lack of innovation, high costs, fragmented practices, low social and environmental awareness, and regulatory challenges. One major issue identified was the significant gap in educational programs, specifically focused on circular business practices, which prevents the sector from maximizing the added value of these sustainable solutions. Additionally, the absence of a strong market for innovations based on circular economy practices in olive oil sector presents a key challenge.

1.3. Recommendations

Sustainable practices in the olive sector are key to minimizing the environmental impact of the olive oil production in Spain, Italy, Greece, Portugal and Croatia. By adopting ecological agriculture, efficient use of water, energy-efficient technologies and strategies for effective management of olive by-products/waste, countries could ensure that olive oil production remains environmentally responsible and economically viable for future generations. The recommendation for the more successful development of the olive by-product/waste market is to establish uniform terminology and legislation in the sector of olive by-products/waste.

Moreover, educational programs related to circular practice in olive sector as well as practical training opportunities, such as internships and workshops in companies that have already adopted circular practices, should be increased to provide students with hands-on experience. Lastly, the report stresses the importance of supporting research and innovation in circular economy through partnerships between educational institutions, research centers and industry stakeholders, fostering innovations and knowledge dissemination.

These initiatives would boost sustainability, lower environmental impact, and increase the economic resilience of the sector.

2
Introduction

2. Introduction

2.1. Overview of the Olive Sector

All five countries involved in this project have a huge influence in the olive oil industry and some of them are one of the world's biggest olive oil producers. According to the statistical data from International Olive Council, the biggest olive oil producer in 2022/23 in Europe was Spain with 665,800 tons produced, followed by Greece (345,000 tons), Italy (240,900 tons) and Portugal (126,000 tons). Croatia has the smallest production of all the countries involved in CRICOLIVE project, with estimated 5,100 tons of olive oil produced in 2022/23 (IOC, 2023). According to the Ministry of Agriculture, Fisheries, and Food of Spain, Spain is positioned as the leading country in the production, commercialization, and export of olive oils, with average sales of 1,400,000 tons per year in recent seasons, 62% of which are destined for the export market. It boasts 2.75 million hectares of olive groves, representing 57.3% of its agricultural area (MAPA, 2024). Of these olive groves, 93% are dedicated to olive oil production, with the remaining 7% used for table olives (CaixaBank Research, 2024). Italy is the world's second exporter and producer of olive oil. Portugal represents 6% of Europe's olive grove area and has potential for even more expansion.

As the olive sector grows, so does the amount of olive by-products and waste, which presents challenges, but also opportunities for sustainable practices. The main by-products in the olive growing and olive oil production sector are olive pomace, wastewater from the oil mill, olive pits and olive leaves and branches. Management of these by-products is gradually developing, driven by environmental regulations and increasing awareness of sustainable practices.

2.2. Objectives of the Report

The aim of this report is to summarize and highlight the current circular practices and technological gaps in the olive oil sector, main challenges, issues, gaps and trends found in the investigation carried out in Spain (D2.1 National Report on the current situation in the olive oil sector – Spain), Italy (D2.1 National Report on the current situation in the olive oil sector – Italy), Greece (D2.1 National Report on the current situation in the olive oil sector – Greece), Portugal (D2.1 National Report on the current situation in the olive oil sector– Portugal) and Croatia (D2.1 National Report on the current situation in the olive oil sector – Croatia) and to encourage adaptation of the provision of vocational education and training to the emerging needs of circular business skills. This report is part of Work Package 2 (Identification of olive sector circular needs and emerging skills and/or professions for transition of the olive oil sector to a circular economy in the 5 countries) of the CIRCOLIVE project (Developing skills for introducing circular business models and digital technologies in the olive oil sector) and represents deliverable D2.2 (Comparative Research Report on the current situation in the olive oil sector).

The review of the available literature and the analysis of the collected data determined the current state of the olive growing sector, which will be used as basis for further project activities and the creation of a curriculum for vocational education and training on circular business skills in the olive sector.

3
Methodology

3. Methodology

The chapter describes the methods of data collection and their analysis. The aim of the chapter is to inform the reader about the methodology used and the possibility of repeating the study using the same methodology.

3.1. Data collection methods

The data was collected from two data sources: primary and secondary data sources. Primary data collection involves the process of preparing tools for data collection and collecting data from a planned sample of respondents. Three data collection instruments were prepared for the purposes of this study: a questionnaire and two interview reminders.

The questionnaire was designed with the aim of collecting quantitative data on a sample of olive grove owners which produce oil in service mills, and a sample of olive mill owners who own or do not own olive groves. The questionnaire (ANNEX 1: Online survey targeting MSMEs in the olive sector) contained multiple-choice questions, closed questions, open questions and questions in the form of a Likert scale. The questions related to numerical production indicators, the use of tillage techniques, the treatment of plant residues in olive groves, methods and capacities of olive processing, the treatment of by-products after olive processing and questions on the circular economy in olive growing. The planned sample size was 30 respondents in Spain and Italy, 20 respondents in Greece and Portugal and 10 respondents in Croatia. However, during investigation data was collected from 30 respondents is Spain, 31 respondents in Italy, 22 in Greece, 25 in Portugal and 18 respondents in Croatia (Table 1). Respondents were classified into 3 categories: 'olive growers' category, 'olive growers and olive mills owners' category and 'olive mill owners' category. The questionnaires were collected online via Google forms.

Two interview reminders were also prepared for the qualitative data collection. One interview reminder was prepared for experts in the agri-food sector (ANNEX 2: Structured interview with circular business agro-food experts/professionals). The other one for providers of education in Croatia (ANNEX 3: Structured interview with VET providers). The reminders contained open questions with sub-questions so that the interview could be conducted as efficiently as possible. The planned sample size was 5 respondents in all countries except Croatia (2 respondents) for experts in the agri-food sector and 5 respondents in all countries except Croatia (2 respondents) for providers of education. All planned sample sized interviews were conducted, while Spain collected one additional interview with expert in the agri-food sector. Interviews were conducted face-to-face with respondents and through an online meeting. The transcripts of the conversation were made. Each respondent has voluntarily and expressly consented to the collection and further processing of personal data and has voluntarily agreed to answer questions for the purpose of research within the CIRCOLIVE project. Each respondent has confirmed this with their signature in the documents: a) Statement related to giving consent for the processing of personal data and b) Information form for participation in research – personal informed consent.

Table 1. Description of the sample of respondents who participated in the online survey (N=126)

	Spain		Italy		Greece		Portugal		Croatia	
Variable	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Number of respondents	30	100	31	100	22	100	25	100	18	100
Gender										
Male	18	60	26	83.9	16	72.7	20	80	14	77.8
Female	10	33.3	4	12.9	5	22.7	5	20	4	22.2
Prefer not to answer	2	6.67	1	3.2	1	4.6	0	0	0	0
Age										
Up to 36	4	13.3	4	12.9	7	31.8	5	20	6	33.3
37 - 56	16	53.3	10	32.3	10	45.5	15	60	4	22.2
57 and more	10	33.3	17	54.8	5	22.7	5	20	8	44.5
Education										
High school and lower	13	41.9	23	74.2	7	31.8	1	4	4	22.2
Bachelor degree	14	48.4	3	9.7	11	50	1	4	5	27.8
Licenciatura degree	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	16	64	n.a.	n.a.
Master degree	2	6.5	5	16.1	2	9.1	5	20	7	38.9
PhD	1	3.2	0	0	2	9.1	2	8	2	11.1
Enterprise size										
Micro (<10 employees)	28	93.5	27	87.1	19	86.4	16	64	12	66.7
Small (<50 employees)	20	6.5	4	12.9	2	9.1	7	28	5	27.8
Medium sized (<250 employees)	0	0	0	0	0	0	2	8	1	5.6
Large sized (> 250 employees)	0	0	0	0	1	4.5	0	0	0	0
Agriculture is in the household										
The only source of income	10	32.3	7	22.6	3	13.6	3	12	7	38.9
Predominant source of income (> 50%)	9	29	5	16.1	4	18.2	12	48	2	11.1
Additional source of income (< 50%)	11	38.7	19	61.3	15	68.2	10	40	9	50

n.a. – not applicable

Secondary data are ready-collected data that come from various sources, e.g.: statistical yearbooks, available studies, databases, scientific papers, technical literature, etc. When using this data, the source is always cited in the report and the list of references for used sources can be found in chapter 13 of this Report.

3.2. Data analysis methods

After the data collection was completed, the data analysis was carried out. Quantitative data collected through questionnaires were analyzed using descriptive analysis and response frequencies. The data are presented in the form of tables, graphically through graphs and descriptively.

The data collected through the interviews were processed through a content analysis. The interviewees' answers are presented in the form of a description with reference to the type of interviewee in the interview (Interview with education stakeholder; Interview with by-products/waste from olive sector stakeholder; Interview with olive growing and oil production stakeholder).

4

National Context

4. National Context

4.1. Geographic and Climatic Overview

The olive sector in Spain, Italy, Greece, Portugal and Croatia thrives in the Mediterranean climate, with each country benefiting from diverse geographic features – ranging from coastal plains to mountainous terrains – ideal for olive cultivation and producing distinctive regional varieties.

Spain: Much of the Spanish territory enjoys a Mediterranean climate, ideal for olive cultivation, characterized by long hours of sunlight and mild temperatures, especially in regions like Andalusia and Extremadura. The diverse topography also contributes to a variety of olives cultivars, each imparting unique flavour to the oil. What sets Spain from other similar countries apart is its millennia-old tradition of olive cultivation. The introduction of olive trees to the Iberian Peninsula by the Phoenicians dates to around the 8th century BCE. This long history has allowed olive farming to become deeply rooted in the culture and economy of Spain (Food and Agriculture Organization of the United Nations, 2024). Olive cultivation in Spain is characterized by its marked biennial bearing nature, resulting in significant production alternation between campaigns. Production is mainly located in Andalusia, followed by Castilla-La Mancha and Extremadura.

Italy: In Italy, the olive oil production chain is more fragmented than it is in other Mediterranean countries. The Italian olive growing is widespread, especially in the southern and island regions, where there is a concentration of about 80% of the total production. The Italian region that has the greatest extent of land dedicated to the cultivation of olives is Puglia, followed by Calabria and Sicily. Other Italian regions are emerging in the olive oil production during the last years, also due to climate change. The Italian olive growing is characterized greatly by fragmentation, this is due, in part, to the topography of the country, and in part to the low mobility of EC assistance (Maroofnezhad, 2013). Southern Italy exhibits a multifaceted olive landscape, with *Olea europaea* being one of the most strongly connotative species and crops of the Mediterranean basin (Allen et al., 2006; Rühl et al., 2011). 30% of Italian olive groves are located in areas with difficult topographic conditions (Modica et al., 2017), such as steep slopes, where many olive orchards are located in Mediterranean areas (Repullo-Ruibérriz de Torres et al., 2018).

Greece: Greek olive oil quality is highly connected to the climate that the olives are cultivated in. The coastal regions have the preferable climatic conditions needed for the olive trees cultivation and a suitable ecosystem for the trees to grow and bear fruit. Olive groves in Greece are cultivated in the following three climatic zones of Greece: the continental zone of northern Greece, the marine Mediterranean Ionian zone and the Mediterranean mainland zone. Olive groves exist in all regions of Greece and in 50 out of 74 regional units. The greatest part of Greece's olive oil is produced in the Region of Peloponnese, followed by Crete, Western Greece, Central Greece, the North and South Aegean and the Ionian islands.

Portugal: Portugal is situated on the south-western tip of Europe, on the Iberian Peninsula. The country's geography is varied, with a combination of plains, mountains, valleys and plateaus. This topographical diversity directly influences the regional climate and, consequently, the cultivation of olive trees. Portugal has a Mediterranean climate, characterized by hot, dry summers and mild, wet winters. However, the country is also influenced by the Atlantic Ocean, which moderates temperatures and increases humidity in coastal areas, especially in the north. With its diverse geography and predominantly Mediterranean climate, Portugal offers ideal conditions for olive growing, especially in the Alentejo and Algarve regions. However, climate change imposes significant challenges, particularly in relation to rising temperatures and reduced rainfall. Adaptation measures, such as efficient irrigation and sustainable management, will be crucial to ensuring that Portugal continues to have the production of high-quality olive oil.

Croatia: Croatia is a south-eastern European country and with its Mediterranean climate, characterized by hot summers and mild winters, supports olive cultivation along the Croatian Adriatic coast. While, the Velebit mountain range acts as a barrier, preventing this climate from extending far into Croatia's inland regions. As a result, olive groves are found only in this coastal region of Croatia, limiting the range of olive and olive oil production. The characteristics of the olive groves vary between the southern and northern regions of the olive cultivation area. In the southern part, including Dalmatia and the islands, olive cultivation is mostly extensive or semi-intensive due to the stony soils (Sladonja et al., 2012). In contrast, the northern part (Istria) features semi-intensive or intensive olive cultivation on deep or semi-deep "Terra Rossa" soil (Oplanić, 2011).

4.2. Historical Development of Olive Cultivation

The history of olive cultivation in Spain, Italy, Greece, Portugal and Croatia dates back thousands of years, with each region playing a pivotal role in the spread and development of olive cultivation across the Mediterranean, shaping both the landscape and the culture of these nations.

Spain: The historical development of olive cultivation in Spain can also be traced back to ancient times. Introduced by the Phoenicians around the 8th century BCE, olive farming has flourished over the centuries, becoming an integral part of Spanish agriculture. Nowadays, the olive oil sector in Spain is heavily reliant on a robust grassroots cooperative movement, which plays a crucial role in the industry's success. Cooperatives, which are widespread in olive oil-producing regions like Andalusia, serve as a foundation for the sector's economic and social structures. They help small and medium-sized producers pool their resources, gain market access, and improve their bargaining power, which is essential for dealing with both domestic and international markets (CaixaBank Research, 2024). Cooperatives also invest in technological innovations and sustainable practices, and support rural development by helping members adopt environmentally friendly techniques that contribute to the broader goals of circular economy initiatives.

Italy: Comprehensive studies of the presence of olive on the Italian peninsula show records of it there since the Early Holocene. The earliest evidence (ca. 6700–5700 bc) comes from Sicily, where Olea sp. pollen is recorded in the pollen sequences from Lago di Pergusa and Gorgo Basso (Sadori and Narcisi, 2001; Tinner et al., 2009) and olive charcoal has been found in the Mesolithic layers of Grotta dell'Uzzo (ca. 6600–6100 bc) (Costantini et al., 1989). Pollen records from Puglia and Toscana show that olive trees were present there from the 5th millennium bc (Caroli and Caldara, 2006; Di Rita and Magri, 2009; Di Rita et al., 2011). Oil production peaked in the early period of the Roman Empire, mostly in Campania, Lazio and Puglia, where oil facilities were connected to latifundia, great estates owned by the aristocracy (Stika et al., 2008). From the 17th century olive oil sector gained growing importance producing the gradual transformation of arable land into olive groves changing conditions throughout central Italy, providing an important contribution to income from agricultural work, and shaped new landscapes between the woods and villages, thus setting off a process of differentiation in the Apennine areas.

Greece: Regarding Greece, dating back to the Minoan civilization, several findings from Knossos appealed that the Cretan economy was based on olive oil (Tsimidou et al., 2003). But the discovery of petrified olive leaves in Santorini, of an estimated 50.000 to 60.000 years of age, proves that the enduring relationship between Greeks and olive trees has a remarkably long story. The olive tree became a sacred tree when the goddess of wisdom, Athena, during a competition with the god Poseidon for claiming the city of Cecrops, offered it as a gift. Homer referred to olive oil as liquid gold, while Hippocrates noted its healing qualities. In the shadow of tales, traditions and legends, olive is still an integral part of life in Greece.

Portugal: Olive growing in Portugal has a long history that reflects the social, economic and climatic transformations the country has faced over the centuries. The introduction of the olive tree to Portugal dates back to ancient times, probably brought by the Phoenicians or the Greeks during the first millennium BC. However, it was during Roman rule (around 200 BC to 400 AD) that olive growing really took hold in the Iberian Peninsula, spreading to the Alentejo and Algarve regions, where climatic conditions and soils were particularly favorable. During the Middle Ages, olive oil production focused mainly on local consumption. During the 18th century olive growing in Portugal began to gain momentum with the introduction of more modern farming practices and a greater emphasis on the quality of the product. Portugal's accession to the European Community in 1986 brought new incentives and subsidies that helped modernize Portuguese agriculture, making it possible to plant 30,000 new hectares of olive groves (Consulai and Vilar, 2019). From its origins in Roman times to its current status as a leading producer of high-quality olive oil, Portugal has shown a continuous capacity to adapt and innovate. The history of olive growing in Portugal is therefore a narrative of resilience and evolution, with a promising future as the country continues to face the challenges and opportunities of the 21st century.

Croatia: Olive cultivation in Croatia has a history spanning centuries. Based on olive stones discovered near Vranjic (close to Split) and subsequent analysis, archaeologists believe that olives have been present since the 9th century BC (Zadro and Perica, 2007). The spread of olive cultivation along the eastern Adriatic coast can be attributed to the Ancient Greeks and Romans. The thousand-year-old olive trees on the Brijuni Islands, in Kaštel Štafilić and in Lun (island of Pag) (Miljković, 2011) stand as living witnesses of the olive cultivation from ancient times, while archaeological finds such as olive mills, amphoras, and *villae rusticae* further attest to the long-standing tradition of olive growing (Sladonja et al., 2012). The area of olive cultivation and the enhancement of olive production saw notable growth in the early 1980s because of the UNDP/FAO programme (Gugić et al., 2010). Today, the advancement of olive production continues to be encouraged through local and regional initiatives, as well as through funding from European Union sources.

4.3. Regulatory Framework and Government Policies related to olive production by-products

The regulatory framework and government policies related to olive production by-products in Spain, Italy, Portugal, Greece, and Croatia focus on sustainable management, environmental protection, and economic utilization of these by-products. Each country adheres to European Union directives on waste management and circular economy principles, while also implementing national regulations to ensure the responsible disposal, recycling, and potential reuse of olive mill waste, pomace, and other by-products in sectors like energy, agriculture, and cosmetics. These policies aim to promote both environmental sustainability and economic development in the olive oil industry.

The regulatory framework and government policies related to the by-products and waste of olive production in Portugal are an integral part of a broader strategy of sustainability, circular economy and compliance with European Union directives. Regarding National legislation, *Water Law* (Law no. 52/2015), *General Waste Management Regime* (Decree-Law 73/2011) *and Rural Development Programme* (PDR, 2020) established rules and measures for waste management and sustainability of agricultural activities in Portugal. *National Waste Strategy*, *Biomass Valorization Initiatives* and *National Sustainable Agriculture Policy* aim to promote waste recovery and olive by-product management. The **olive pit** in Portugal can be classified as either a by-product or waste, depending on how it is treated after it is generated. The distinction between by-product and waste is made on the basis of the criteria established by *Decree-Law 73/2011*, which regulates waste management in Portugal.

Classification therefore depends on the intended use and subsequent treatment of the pit. If it is reused efficiently, it is a sub-product; if it is discarded without useful application, it becomes waste.

Spain has several relevant regulations and strategies in place to promote the circular economy in the olive oil sector such as The *Royal Decree 553/2020*, which regulates waste transfer; the *CE Action Plan I*, which includes measures to incorporate circular economy principles into other policies and the *Order TED/92/2022*, which establishes the conditions for considering **pomace** from olive mills as a by-product. According to mentioned Order, pomace is considered a by-product if it will be used without further processing other than what is typically industrial, produced as part of an integrated production process, and meeting all relevant health and environmental requirements (Real Decreto 553/2020; Orden TED/92/2022). *Regulation (EU) 2019/1009* related to fertilizers is an example of European regulation that directly affect olive by-product management. In Spain, *Royal Decree 506/2013* on fertilizers and *Law 22/2011* on waste and contaminated soils set frameworks for handling organic waste and environmental protection, complicating compliance but also pushing the sector towards sustainability. Croatia also has some regulations regarding waste management, particularly the *Law on waste management* (NN, no. 84/2021) and the *Law on Fertilizer Products* (NN, no. 39/2023). The most important Italian legislation on the subject is the previous *Prime Ministerial Decree* of 8th March 2002 (DPCM, 2002), in which virgin pomace was considered as a vegetable fuel that may be freely used, while exhausted pomace, which has undergone a chemical process, was categorized as a dangerous waste and was therefore subject to constraints. Subsequently, with the passing of the legislative *Decree no 152* of 3rd April 2006 (D. Lgs 152/2006) and the *Prime Ministerial Decree* of 8th October 2004 (DPCM, 2004), the earlier *Prime Ministerial Decree* of 8th March 2002 was modified and exhausted pomace was categorized as a fuel.

In Croatia*, the Low-Carbon Development Strategy of the Republic of Croatia until 2030 with a view to 2050* (NN, no. 63/2021) suggests potential agricultural measures such as collecting **pruning residues** for use as energy. There is no specific regulation concerning the treatment of pruning residues or weeds in Greece. While there has been a strict prohibition for the burning of arable stubble within the Cross-Compliance obligations and currently the Enhanced conditionality rules, no such restrictions exist for permanent crops. The only restriction currently applied is that of the prohibition of setting fire outdoors (any kind of fire, hence for burning agricultural residues also) for protection against forest fire (usually from May to October).

In Croatia, The Ministry of Agriculture provides guidelines for managing pomace and vegetative water intended for producers in the olive oil and table olive sector with references to various laws and regulations (Ministry of Agriculture, 2024). **Wastewater** is a byproduct of olive oil production, rich in organic matter and phenolic compounds, posing significant environmental challenges due to its high pollutant load.

In Croatia it must be used exclusively in accordance with the principles of good agricultural practice and adequately disposed of in accordance with the *Water Law* (NN, no. 47/2023). A water permit is required for each discharge of wastewater in Croatia, except when the entire amount of these waters is used exclusively on agricultural lands for the purpose of nourishing plants or maintaining and/or improving the physical and/or chemical properties of the soil (Ministry of Agriculture, 2024). Similarly, in Italy, spreading of wastewater on agricultural soil is only possible with previous treatment up to 50 m3/ha for OMW obtained by press and 80 m3/ha for OMW obtained by centrifuge (D.Lvo no. 258, 2000). With the Italian *Law n°574*, the agronomic use of sewage sludge and other wastes is allowed on the ground of their composition and the characteristics of soils. Such use has to be authorised each time by the competent public authority on the ground of simple documentation but subordinate to limitations, verifications and possible sanctions in order to avoid any fraudulent activity that can pollute water sources. This law allowed the direct application of the olive mill wastewaters without previous treatment (Kapellakis et al., 2007). In Spain, liquid effluents can be used under a series of conditions that ensure they do not affect the environmental quality of the area where they are applied (MAPA, 2024). The use of effluents is prohibited on saline or sandy soils, on plots with slopes greater than 15% for woody crops and 10% for herbaceous crops, percentages that can be increased up to 35% for woody crops as long as there is a vegetative cover with a minimum width of 1 meter. Similarly, the maximum permissible limits for the analytical parameters of the effluent for its application on agricultural soils are established (Actualidad Jurídica Ambiental, 2022). In Greece, the treatment of olive oil mills wastes is regulated by the national legal framework. Specifically, the conditions of the *Greek Joint Ministerial Decision* (JMD) 15/4187/266/2012 (Government Gazette 1275 B) as they have been amended by the JMDs 135207/1801/2017 (Government Gazette 4333 B) and 127402/2016 (Government Gazette 3924 B) are applied on the Standard Environmental Commitments (SBC) of industrial activities of olive oil mills. Concerning wastewater derived from olive oil production, according to condition E3-1 of the JMD oil collection, neutralization or any other equivalent method, sedimentation and finally disposal to open evaporation ponds is the proposed treatment method. According to Condition E3-2 of the JMD, olive oil mill wastewater can be used after appropriate pre-treatment process (including oil collection, sedimentation or any other equivalent method) for the irrigation of olive groves or other trees.

5

Olive Production Analysis and Olive Oil Processing

5. Olive Production Analysis and Olive Oil Processing

5.1. Cultivation Practices and Varieties

Olive trees grow slowly, taking four or five years to yield their first fruits and another 10 to 15 years to reach their full capacity. Once established however, the olive trees can live for many years. Every procedure concerning olive farming, from pruning in spring through flowering and harvesting in the late autumn, has a bearing on the quality of the fruit, and thus of olive oil (Lodolini et al., 2023; Saglam et al., 2014). Winter pruning also comes after harvesting to prepare the tree for the next crop. The maturity of the olive fruits plays an important role by affecting both the taste and odor of the oil produced (Mele et al., 2018). Spain, Italy, Greece, Portugal and Croatia have a high diversity of olive varieties, with each country cultivating unique varieties suited to their local climate and tradition, contributing to the distinct flavors of their olive oils and table olives.

In Greece, the olive fruit harvest, via hand-picking, begins in October and goes on for about two months, depending on the olive cultivar and the place it is cultivated. Some olives are suitable only as table olives and others are suitable only to produce oil. For table olive production, green olives are harvested first, followed by the plumped black olives that are among the country's best-known snacks: tight-skinned Kalamata olives with their pointy tip and juicy Amfissas olives that come in a variety of browns, blacks and purples. Last to be harvested is the wrinkled black variety, which may be harvested even in March, as it must mature on the branch firstly and then be cured in coarse salt. Olive varieties in Greece which are most used for olive oil production are 'Koroneiki', which produces a high quality, low acidity and full-bodied extra virgin olive oil; 'Athinolia', which is a variety of olive that matures slowly and is harvested from the end of December until the beginning of January and 'Manakialso', a variety that gives a specific aroma of ripe fruits (apples and tomatoes) to the olive oil (https://approachguides.com/blog/guide-greek-olives-olive-oil/).

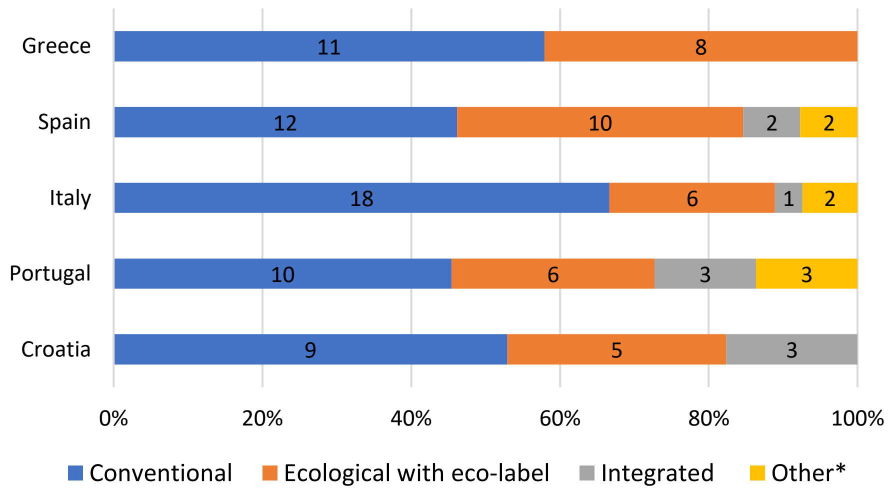
The major olive-growing regions in Portugal are located in Trás-os-Montes, Beira Interior, Ribatejo, Oeste and Alentejo. According to 2019 data, traditional olive groves occupy a total area of 140,000 hectares (37.2% of the total area), with a greater expression in the regions of Beira Interior and Trás-os-Montes. Modern canopy olive groves occupied a total area of 125,000 hectares (33.2% of the total olive grove area) and were represented in all regions of the country (Consulai and Vilar, 2019), although in 2024 they were most prevalent in the Alentejo region.

Italy is currently the leading country for cultivar biodiversity, accounting for over 800 varieties (International Olive Oil Council, 2019; Rotondi et al., 2013). The most widespread olive varieties in Italy, 'Frantoio', 'Leccino' and 'Moraiolo' are used to produce monovarietal extra virgin olive oils (MEVOOs) which are products reflecting the characteristics of a country beyond genetics. Their systematic sensory and chemical characterization has a pivotal role in order to identify quality oils with remarkable diversity and clear identity (Campus et al., 2013; Portarena et al., 2015; Blasi et al., 2019; Klikarová et al., 2020).

In Croatia, the most represented domestic variety is 'Oblica', which is represented by 1,957,230 trees (53.51%), while the most represented of the introduced varieties is the Italian 'Leccino' with 536,553 trees (14.67%). Other well represented domestic varieties include 'Istarska belica' (4.83%), 'Buža' (4.33%), 'Lastovka' (3.46%) and 'Levantinka' (1.88%).

In Spain, olive varieties are distributed across 10 different zones. The main variety in Zone 1 is 'Picual', Zone 2 and 3 'Hojiblanca', Zone 4 'Lechín de Granada', Zone 5 'Manzanilla Cacereña', Zone 6 'Cornicabra', Zone 7 'Blanqueta', Zone 8 'Empeltre', Zone 9 'Farga' and in Zone 10 'Arbequina'. Among mentioned varieties, two main olive varieties are: 'Picual', renowned for its high oil yield and robust flavour, and 'Arbequina', which is valued for its mild taste and high adaptability. Cultivation practices vary regionally, with Andalusia, Castilla-La Mancha, and Extremadura being the primary olive-growing areas.

The diversification of practices and the adoption of more sustainable techniques in olive production are trends that are likely to continue to grow, especially with the pressure to reduce the environmental impact of agricultural production. Data on the methods of olive production were collected during the primary research conducted in 5 countries (Spain, Italy, Greece, Portugal and Croatia) as part of the CIRCOLIVE project on a sample of 'olive growers' and 'olive growers and olive mill owners'.



Other* - Sustainable (Portugal), Ecological without the label (Italy), Biodynamics with Demeter label (Spain)

Figure 1. Technology used in olive groves ('Olive growers' and 'Olive growers and olive mill owners' categories, N=111)

Regarding the technology used in the olive groves, majority of respondents from all countries use principles of conventional agriculture, followed by ecological cultivation method. Smaller fraction of respondents uses integrated production techniques or other similar practices (Figure 1).

When choosing answers for **technological interventions related to the circular economy**, 'olive growers' and 'olive growers and olive mill owners' could choose several answers and a combination of interventions was possible (e.g. mulching and inert plant cover from cut grass). Out of Spanish respondents from category 'olive growers', most of them use drip irrigation and water consumption control, while the main practices for respondents from category 'olive growers and olive mill owners' include the use of organic fertilizers followed by the use of inert plant cover derived from crushed pruning and the incorporation of pruning residues. Technological intervention mainly used in Portugal is grass cutting followed by inert mulching from cut grass. Also, in Greece and Italy, the most popular technological intervention includes grass cutting, followed by the use of organic fertilizer. Croatian respondents overall, as main technological intervention in the olive grove, use organic fertilizers and mulch the residues from pruning olive trees and grass-cover their olive groves.

When choosing an answer about the **handling of pruning residues**, respondents from categories 'olive growers' and 'olive growers and olive mill owners' could choose several answers, and their combination is possible (e.g. firewood and production of useful and decorative items). Overall, evaluation of survey results conducted in 5 countries showed that majority of respondents mulch their pruning residues, use them as firewood or use controlled burning with or without returning the ashes to the soil. Least popular methods of dealing with pruning residues include production of useful and decorative items, and the use for pharmaceutical and food industry.

When **managing the soil**, respondents mostly favor mulching, which involves covering the soil with pruning waste or permanent grassland (Figure 2). This practice is beneficial for retaining moisture in the soil, controlling weeds and improving soil fertility, reflecting a more ecological and sustainable approach. The same number of respondents overall uses methods of soil cultivation and combination of it with mulching. Soil cultivation, although effective for some operations, may be less sustainable in the long term due to the possible impact on soil structure and increased erosion. Some respondents choose to combine different soil management techniques, possibly in order to optimize the benefits of each method and minimize their negative impacts.

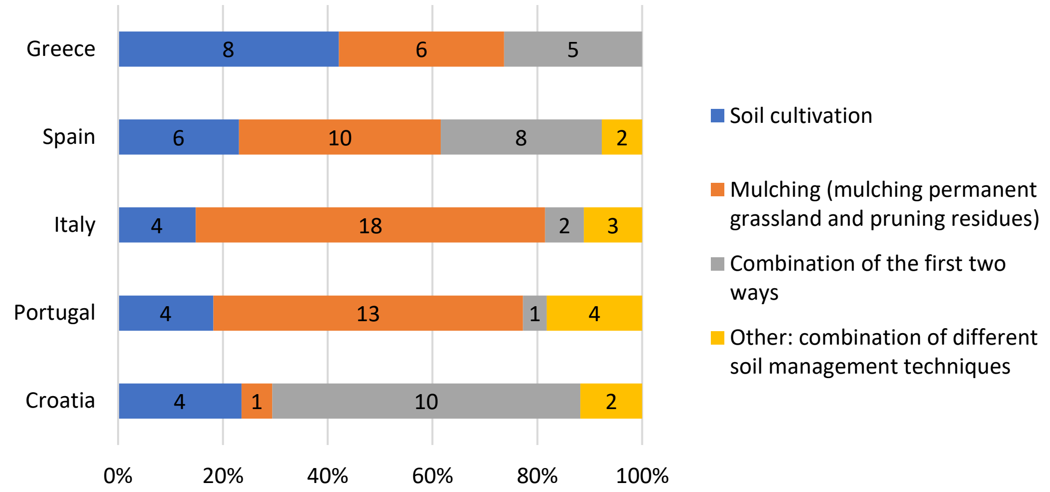


Figure 2. The method of soil management in an olive grove ('Olive growers' and 'Olive growers and olive mill owners' categories, N=111)

During the regular **pruning of olives**, a by-product is created in the form of leaves and branches, and its quantities depend on the age and lushness of the olive trees, as well as on the number of prunings carried out annually in the olive grove. It is a common practice and is essential to maintain the health of the tree, control growth and improve fruit production. According to the results of research within the CIRCOLIVE project, winter pruning is mostly done every year by olive growers and mill owners in 5 investigated countries (Figure 3).

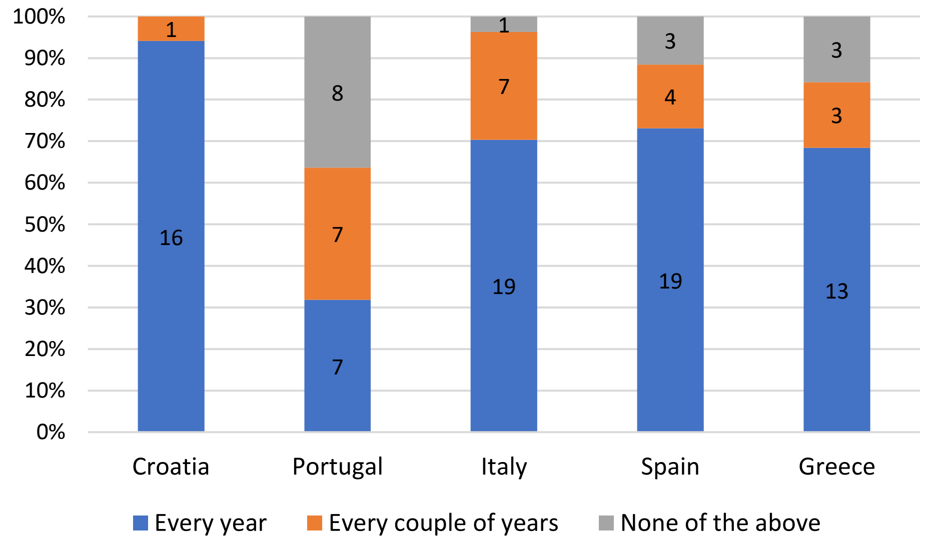


Figure 3. Intensity of winter pruning ('Olive growers' and 'Olive growers and olive mill owners' categories, N=111)

On the other hand, summer pruning, which is lighter and focused on removing new shoots, is carried out every year mostly in Croatia, Italy and Greece, while in Portugal and Spain, most growers choose not to carry out summer pruning (Figure 4). This may be due to prioritizing more robust winter pruning practices, or simply a management strategy that minimizes summer interventions. Overall, summer pruning practices vary significantly, which may indicate different regional approaches or grower-specific challenges.

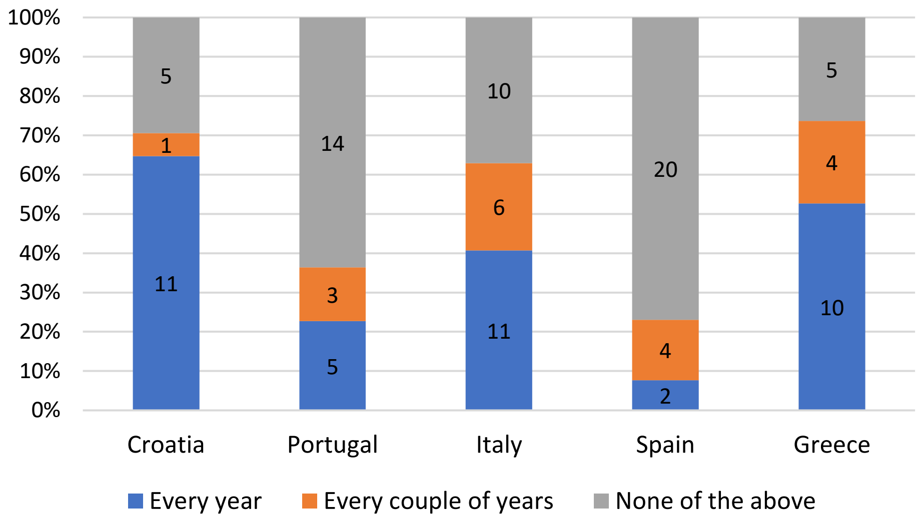


Figure 4. Intensity of summer pruning ('Olive growers' and 'Olive growers and olive mill owners' categories, N=111)

5.2. Olive Oil Extraction Methods

Olive oil extraction methods which can be used in olive mills are:

1**. Traditional pressing** - where the ground paste is placed between pressing mats and is subject to pressure in order to extract the mixture of oil and water. This mixture is then poured into a vat or a holding tank to rest until, due to gravity and the different densities, oil is separated from the water.

2. **Centrifugation method -** conducted by two different types of decanters:

(a) three-phase centrifugation system during which 1 liter of water is added per kg of paste and is subsequently placed into a horizontal centrifugal machine, where the solid is separated from the oily phase. This phase of unpurified oils then passes into a vertical centrifugal machine, where the oil is separated from the vegetable water. This process results in the production of three streams i.e. olive oil, wastewater and pomace (dry pomace). The produced pomace is dry and can be used either for obtaining pomace oil or can be treated as a by-product/waste.

(b) two-phase centrifugation system, a process that is more advanced. Specifically, it is based on a two-phase decanter and is the same as the three-phase process, but instead of adding water before the horizontal centrifugation, the vegetable water produced is being recycled, leading to lower energy costs, less water waste and a higher extraction rate of olive oil (output/input ratio). This process results in the production of olive oil and wet pomace. These wastes are not considered as much of a disposal problem compared to the wastewater produced from a three-phase system. They are usually dried onsite to obtain a pomace with less than 50% of water. However, drying process is costly and greenhouse gasses and fumes are produced (Niaounakis and Halvadakis 2006).

Olive oil extraction in Spain employs both traditional and modern methods. In the last 30-35 years, the process of oil extraction in the mill in Spain has undergone various and very significant technological changes. From the traditional olive press, the process evolved to continuous extraction using a three-phase decanter (oil, pomace, and olive mill wastewater), and in recent years, to a two-phase decanter (oil and wet pomace), and occasionally to a second centrifugation.

Italy has a high number of olive oil mills (more than 4,000) and more than 90% of them process less than 1,000 tons of olives but produce only 44% of oil, with the remaining larger mills accounting for 56% of total production (ISMEA, 2024). Among the olive mill operators who completed the questionnaire, the average mill capacity in Italy is 1,404 kg per hour.

According to a sectoral report of National Bank of Greece from 2015 the most commonly used process for oil extraction in Greece at a rate of 80% was the three-phase centrifugation system, whereas traditional pressing systems was still used at a percentage of 18%. Since then and according to recent data reported by the Ministry Environment and Energy (https://wfdver.ypeka.gr/el/consultation-gr/2revision-consultation-gr/) the majority of the mills in Greece function through two-phase centrifugation systems.

Portugal, according to data from Portugal's National Statistics Institute (INE, 2023), has a total of 455 olive oil mills, of which 69% are industrial mills, almost 21% are cooperative mills and 10% are private mills. Eight of the ten mills in the world that mill the largest quantity of olives are located in Portugal, with capacities of between 60 and 110 million kg of olives per campaign. Each of these mills has several production lines, which include receiving the fruit, prior collection, milling, separation, filtration and storage.

In contrast, Croatia does not have official data on the number of oil mills and their capacity, so for the purposes of CIRCOLIVE project, different sources were compared and a minor discrepancy was noticed between them, most likely due to different data collection methods. Therefore, for the number of olive mills in Croatia, is used the information about 182 mills for processing olives into oil. Among the survey respondents in Croatia, there were 50% of oil mills with a processing capacity of 500 – 2,000 kg/hour, followed by oil mills with a capacity of more than 2,000 kg/hour (37.5%). It is known that the extraction of oil from olive fruits in Croatia is almost exclusively carried out using centrifugal systems, which agrees with the result of this investigation (75% of olive mills surveyed use 2-phase system, while the rest uses 3-phase system). The traditional pressing process is used only sporadically, and considering the much lower processing capacity, the share of traditional presses in olive processing in Croatia is negligibly small (D2.1 Croatia, 2024; Koprivnjak and Červar, 2010).

Regarding the **type of centrifugal separation**, in the oil mills surveyed in the 5 countries, results show that two-phase system of centrifugal separation is the predominant extraction method used (Figure 5). In Spain, 25% of respondents from category 'olive mill owners' still use three-phase centrifugation system as well as more than half of the Greek respondents (D2.1 Spain, 2024). That is possibly due to different operational needs or resource management strategies. Interestingly, only one of all respondents, situated in Spain, uses a combination of both extraction methods.

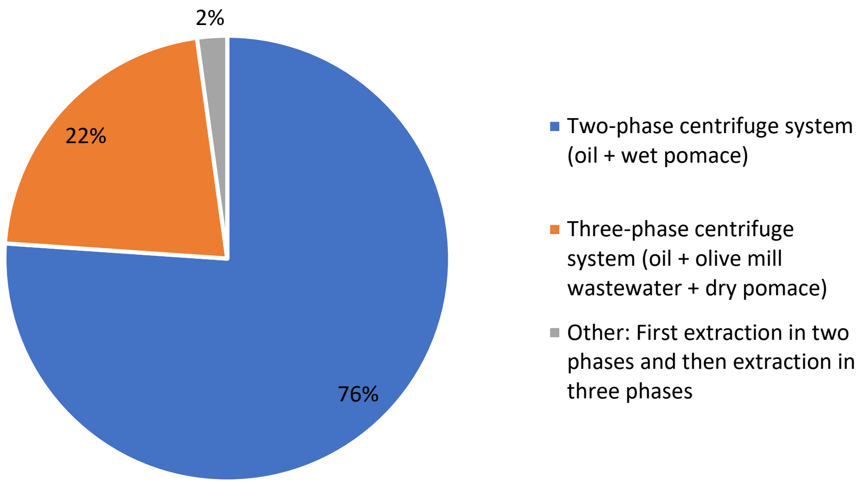


Figure 5. Division of oil mills with regard to the type of system for centrifugal separation of oil, pomace and water in Spain, Italy, Greece, Portugal and Croatia ('Olive growers and olive mill owners' and 'Olive mill owners' categories, N=46)

5.3. Cultivation area, Yield Trends and Production Statistics

According to the Olive Oil Market Report (2023), Spain is the largest olive oil producer globally, with a total cultivation area of approximately 2.8 million hectares. The total olive oil production in Spain for 2023 is estimated to be around 1.8 million tons (Ministry of Agriculture, Fisheries, and Food of Spain, 2024). Spain is followed by Italy, whose production covers approximately 1.14 million of ha, 80% of which are located in the southern zone of Italy, where in particular Puglia is responsible for around 340,000 ha followed by Calabria and Sicily. These three regions account for more than 70% of Italian olive oil production (Seval Kurtoğlu et al., 2024). Greece, another large olive oil producer, in 2022 produced 461,839 tons of table olives and 2,747,069 tons of olives for olive oil (ELSTAT, 2022). According to the International Olive Council data, from 2016 to 2023, an average of 223,500 tons of olive oil were produced in Greece ranking it (9%) in the third place of the foremost producers of olive oil in EU after Spain (49%) and Italy (12%). According to the latest EU data, the olive oil production in Greece between October 2023 and January 2024 was up to 131,500 tons, while the final production of the season is expected to amount to 155,000 tons (MS declarations - Commission Regulation R 2017/1185 Art.12). Over the years, in Portugal, there was a slight increase in olive grove area, which in 2020 reached a maximum of 380,852 hectares, corresponding to an increase of 7% in relation to the olive grove area 20 years ago (Consulai and Vilar, 2024). Currently, and because of the modernization of olive groves and mills, national olive oil production has been growing, reaching 1,350,238 tons in 2021. In 2022, production was 74% lower than in 2021, due to the fact that it was a year of counter-harvest and drought. In 2022, the Alentejo region accounted for 87% of national olive oil production (Consulai and Vilar, 2024). Portugal's production went from 24,600 tons in the 2000/01 harvest year, representing 1% of world production, to producing around 210,000 tons, with a world weight of 4%, in the 2021/2022 marketing year, representing growth of 320%, which is higher than the world average (140%) (Consulai and Vilar, 2024).

Croatia is small-scale olive oil producing country, whose area under olive groves constantly increases, from 11,398 ha in 2000 to 19,900 ha in 2022, which represents an increase of 75% (Gugić, 2010). In 2022, the production of olive fruits amounted to 40,130 tons, which, compared to the year 2000, is an increase of about 147%. The yield of olives fluctuates from 1.20 tons/ha, which was recorded in 2021, to 2.13 t/ha in 2009. Such deviations in the yield of olive fruits are, to the greatest extent, a consequence of the action of natural conditions in a particular production year (Table 3 in D2.1 Croatia, 2024).

6

By-products and Waste Production in the Olive

6. By-products and Waste Production in the Olive Sector

As the production of olive oil grows in the world, so does the generation of by-products and waste materials, presenting both challenges and opportunities for sustainable practices. The main by-products of olive oil production are olive pomace, olive mill wastewater, pits, and olive leaves and branches (Delgado et al., 2022). It is necessary to study how to increase the storage and processing capacity of these by-products in the mills, as well as how new industrial units should be authorized and built (Consulai & Vilar, 2024). The management is developing, driven by environmental regulations and increasing awareness of sustainable practices. For example, the use of olive pomace for energy production through combustion or biogas production is increasingly widespread in the world (Christoforou and Fokaides, 2016). In addition, advances in wastewater treatment technologies, such as anaerobic digestion and membrane filtration, offer potential solutions to reduce its environmental impact while harnessing valuable substances such as polyphenols and irrigation water (Mehta et al., 2021). Despite these advances, challenges remain. The small and fragmented nature of olive oil production in some countries makes it difficult to implement centralized solutions for waste management (Alfano et al., 2009). Furthermore, the economic viability of converting by-products into commercially viable products depends on the development of appropriate technologies and market demand (De Corato et al., 2018). In conclusion, by-products and waste materials from the olive oil production sector represent significant environmental challenges, but also offer opportunities for innovation and sustainability (Klisović et al., 2021). By adopting integrated waste management strategies and investing in research and development, countries can improve the sustainability of its olive oil industry and contribute to the circular economy. In parallel with the increase in the volume of olive production, continuous investments in the education of olive growers and the modernization of production technology is necessary to ensure the production of high quality olive oil.

6.1. Olive Leaves and Branches

Olive leaves and branches, as residues of olive production, are created during the regular pruning of olive trees, and the rest of olive leaves are also accumulated during the extraction of leaves from olive fruits before processing olives into oil (Novoselić et al., 2021). Due to their **rich content of phenolic substances**, leaves become an interesting raw material for the food, pharmaceutical and cosmetic industries (Markhali et al., 2020, Romero-Marquez et al., 2023).

Pruning biomass represents the total average annual pruning biomass for olive trees and in their mature phase amounts to 0.7803 tons of dry matter per hectare. This biomass represents the branches that are pruned annually for maintaining tree health and fruit production. The fallen leaves contribute to the annual leaf biomass, with each tree shedding an average of 6.21 kg of dry matter per year. This biomass can be managed similarly to prunings, either left in the field to decompose and enrich the soil, collected for composting, or used as mulch. The fallen leaves represent an additional source of organic material that can be used to improve soil fertility if managed appropriately. Given that, evergreen trees like olives renew their leaves roughly every three years, this biomass can be a consistent **source of organic material**.

Additionally, the use of olive leaves and branches as inert mulch demonstrates that this is a mitigating practice and is part of a strategy that can improve soil properties, reduce CO_2 emissions and increase the soil's capacity to store carbon (Consulai & Vilar, 2019). According to the results of the SustainOlive project (https://sustainolive.eu, 2023), it can be seen that when the soil receives no addition of organic carbon, apart from natural leaf fall, soil organic carbon (SOC) drops to 80% of its initial rate after 30 years. Thus, when tree pruning is shredded and applied to the soil, along with the fallen leaves, carbon is lost by around 2%.

In Italy, from mature olive trees, depending on their structure and size, an average of between 10 and 30 kg of these wastes are produced each year. Considering Italian olive growing area and the average number of trees per hectare, annual biomass production would be 1.87 million tons (Buttol et al., 2018). A common practice in rural areas of Spain consists of burning branches and leaves in large piles in the open air. However, although burning pruned olive branches may seem like an acceptable and common practice, it can have serious consequences for both human health and the environment. Also, the droughts and lack of rainfall make it even more urgent to regulate the burning of pruned olive branches, as it can be a fire risk even in autumn and winter in areas of Andalusia such as Córdoba or Jaén, and specifically in the Sierras Subbéticas Natural Park in Córdoba (Ministry of Agriculture, Fisheries, and Food of Spain, 2024).

During the interviews conducted on the CIRCOLIVE project, stakeholder in the business with by-products/waste from olive sector in Croatia stated that he processes olive branches and gets about 70 kg of pellets from 100 kg of branches. A stakeholder in the olive growing and oil production in Croatia stated that he owns a mulching machine in which he processes **the branches** and **mixes them with pomace compost** and **returns them to the olive grove**. The 6 interviews conducted in Portugal with experts/professionals in the agri-food sector from circular economy companies revealed that the majority of olive leaves and branches are used for **animal feed**, for rabbits and cows, composting, shredding for mulching, or burning on site or **for heating purposes**, mostly in the north of the country. Similar practices are conducted also in Italy, where growers use part of the leaves for animal feed, the thinner branches for **pellet production**, while the thicker ones are sold to furnaces. Notably, one of the interviewees from Italy attempted to produce a liqueur from olive leaves but, due to low market demand, the production was subsequently discontinued.

6.2. Olive Pits

The olive is composed of 85% pulp and 15% pit. The olive pits are a valuable and underutilized by-product of olive production and can be utilized in two fundamental ways: to generate energy and to obtain non-energy chemical products. They are natural products, free from chemicals and have a high heating power of 5,153 kcal/kg. Although a growing number of producers are exploring their potential, there is still a long way to go for the widespread adoption of technologies that can facilitate the separation and valorization of this waste. One of the most significant applications of olive pits is their use as biofuel (Sanchez et al., 2015). Other than that, the pits have potential for charcoal production (pits can be carbonized to create a more sustainable alternative fuel) or the use for animal feed (after processing, they can be used as a feed supplement). In agriculture, olive pits can be used as a natural material to improve soil structure (Brunetti et al., 2005). Crushed seeds can be applied as organic mulching material, which helps conserve soil moisture, reduce erosion and prevent weed growth. This approach is particularly useful in arid coastal areas, where water conservation is critical. Olive pits, as a valuable source of bioactive phenolic compounds, oleic acid, plant proteins and dietary fiber, also have potential for use in cosmetic and pharmaceutical purposes (Galitsopoulou et al., 2022).

Traditionally, the olive pit has been used in boilers in olive-related industries, such as oil mills and extractors, as well as in other sectors like ceramics and farms. In Croatia, there are examples of using olive pits for heating residential buildings or industrial plants, which reduces the need for fossil fuels and contributes to the reduction of greenhouse gas emissions (Medic, 2015). In Spain, the number of companies dedicated to utilizing this material and transforming it into eco-friendly fuel has significantly increased in recent years, becoming a highly profitable business. In Italy with the passing of the *Prime Ministerial Decree* of 8th October 2004 pits from olive pomace were included in the category of biomass fuels as vegetable matter produced exclusively from the mechanical processing of agricultural products (ISTAT, 2009). In this way, CO_2 emissions into the atmosphere are reduced, there is less dependence on fossil fuels, the environment is more respected and the olive oil production cycle is closed with zero waste (Consulai and Vilar, 2019).

Another possibility for using olive pits is to include them in composting processes, although they are slower to degrade due to their rigid structure. Its use depends on local practices and technological acceptance in the producing regions. In the future, it is expected that further technological innovations will allow greater integration of pits into circular economy systems, especially with the increased demand for renewable energy sources and sustainable agricultural practices.

According to the data obtained through surveys on a sample of olive growers and olive mill owners, the following data was obtained on **the method of handling the pit** during processing in Spain, Italy, Greece, Portugal and Croatia. Slightly higher percentage (57%) of survey respondents do not separate the pit during processing (Figure 6). This suggests that the use of pits as a by-product is still in the process of being adopted, possibly due to technological and monetary limitations, or the lack of infrastructure for biomass utilization. Greece is the only country where none of the respondents separate the pit (Figure 7). In the tested sample, out of the respondents that do separate the pit, the separation is done in the phase after the extraction of oil from dry or wet pomace.

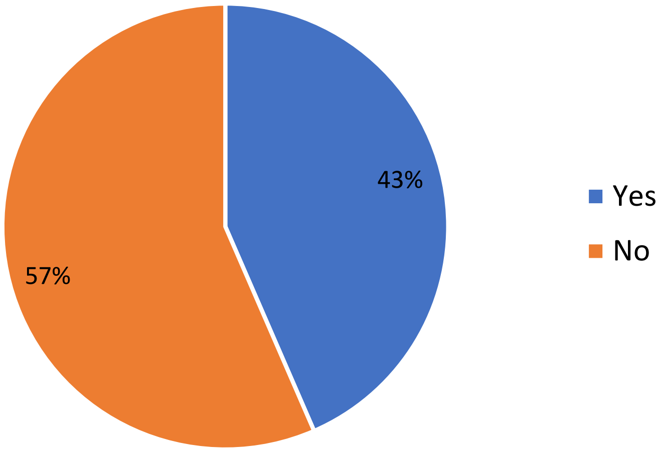


Figure 6. Separation of pits from the olive fruits in the olive mill in Spain, Italy, Greece, Portugal and Croatia ('Olive growers and olive mill owners' and 'Olive mill owners' categories, N=46)

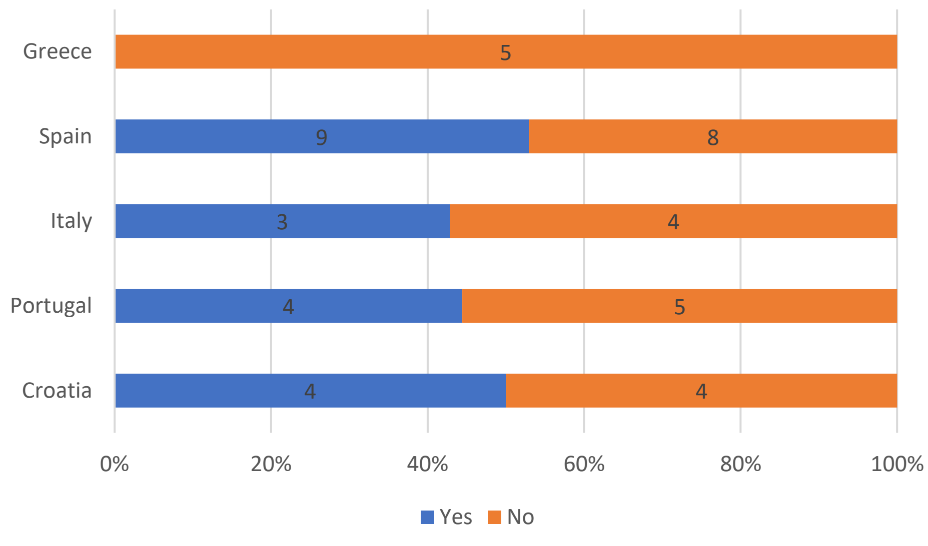


Figure 7. Separation of pits from the olive fruits in the olive mill ('Olive growers and olive mill owners' and 'Olive mill owners' categories, N=46)

Below are the results of the CIRCOLIVE qualitative research, i.e. the interviews conducted with stakeholders in the olive growing and oil production. In Croatia, the interviewed stakeholder in the olive growing and oil production uses olive pits on agricultural land **as mulch**. During the interview, he stated that 10-12% of the total weight of the olive fruit is made up of the olive pit, which can vary from year to year.

Portuguese stakeholders use olive pits **as biomass**, to run the boilers and heat the water in the mill, and at the same time commercialize part of this by-product. They agree that it is necessary to invest in the acquisition of technology that will allow the pit to be extracted before the olives are milled. One of the stakeholders in Portugal stated that the installation of a very modern ginnery on the property in 2024 will make it possible to use the olive pits **for biofuel** and they believe that they will be able to obtain around 100,000 kg of olive pits this year, with part of this by-product going to the estate for self-consumption and the rest for sale. The data collected from the interviews in Italy revealed that all olive pits extracted from the pomace are used as fuel **for energy production**. This is either separated within the olive mill's ecosystem, where the generated energy is used for heating the facilities and washing water, or, in most cases, it is separated from the pomace by third-party companies and used as fuel to produce energy. One of the interviewees mentioned that within the olive mill ecosystem, the pomace is not completely deprived of pits, as the pomace processors to whom it is sold prefer it this way.

According to the CIRCOLIVE field research results, the most common practice in Greece nowadays is the usage of olive pits as an energy source in its original form. Thus, it is generally believed that the amount of olive processing waste can be significantly reduced and a natural, renewable energy source can be obtained. However, the majority of the respondents from the survey in Greece did not realize that olive pits have a higher energy value compared to wood. It is also unclear to many of them whether high investments are required for the processing of pits. Selected respondents from Spain predominantly use olive pits as an energy source, which highlights a strong preference for energy generation. Additionally, some 'olive mill owners' consider the **production of pellets or briquettes and biomaterials**. Interestingly, a small part of olive producers indicate that they do not pit their olives or do not use the pits at all.

6.3. Olive Pomace (2-phases and 3-phases)

Considering the technology of separating the oil from the rest of the ground olive fruits and the organization of production, several different types of residues can be named, which can be considered as by-products or waste depending on their further usage. The composition of the residues from the olive mill will depend to the greatest extent on the initial average composition of the olive fruits and on the amount of added water in terms of dilution and, of course, on the extraction technology.

The process of extracting virgin olive oil from olive fruits produces, in addition to oil, the remains of virgin olive oil production, which can be categorized in different ways depending on the purpose. In terms of processing and utilization for agronomic purposes as a soil improver after oil extraction, the following types of by-products remain, which are quantitatively the most significant and therefore the biggest problem for disposal, i.e. a challenge for processing and utilization:

- two-phase olive pomace (wet pomace)
- three-phase olive pomace (dry pomace)
- liquid residue of three-phase olive processing (wastewater from olive processing).

Olive pomace constitutes a raw material for olive–pomace oil production. It is a moderately acidic, semi-solid material, generally consisted of 50–70% water, 2.5–3% residual oil retained in the pulp, significant amounts of cellulose, hemicellulose and lignin, inorganic compounds, and organic matter, including proteins, polyphenols, polyalcohols, pigments, sugars, and fats (Tsantila et al., 2007; Lopez Pineiro et al., 2008). Due to its organic charge it presents phytotoxic properties and thus, it requires special techniques for its treatment (Nunes et al., 2020). Pomace produced from two-phase systems is characterized by higher humidity compared to that from 3-phase systems.

On the average, for each ton of olive oil produced, 2.33 tons of olive pomace are obtained (Intini et al., 2014). Depending on how it is treated, olive pomace can be a valuable source of energy and fertilizer, with the following characteristics:

- Use as a fertilizer: After the composting process or appropriate treatment, the pomace can be applied directly to the soil as a fertilizer, promoting moisture retention and improving soil quality. Composting can thus reduce spending on mineral fertilization and be an alternative to it, improving poor soils and solving erosion problems. It should be noted, however, that direct use without treatment can cause phytotoxicity problems due to the phenolic compounds present.
- Biomass production: Olive pomace can also be dried and used as biomass in heating systems or to generate electricity, taking advantage of the high calorific value of the waste.

SustainOlive project (https://sustainolive.eu, 2023) results showed that soil organic carbon (SOC) levels improved with the application of composted olive pomace and manure, although to a lesser extent than with herbaceous cover. It was also estimated that after 30 years, soil organic carbon is 55% higher in olive groves with organic soil application (53 tons per hectare), compared to the control where conventional practices were followed (34 tons per hectare). In olive groves whose soils are relatively unchanged and where there is a wide variety of types of organic matter (olive pomace compost and crushed pruning waste, among others), a much more diverse and biologically active soil microfiber develops, having enormous value for the farmer in ecological, productive and economic terms. It could therefore be said that olive pomace, whether from a two-phase system or a three-phase system, offers significant opportunities for the production of valuable by-products such as biomass and organic fertilizers. However, proper management is mandatory to avoid environmental impacts, especially with regard to the management of wastewater and phenolic compounds. With appropriate technologies and sustainable management practices, olive pomace can be transformed into a valuable resource, rather than a problematic waste product, contributing to the circular economy in olive growing.

Regarding **pomace handling**, it can be also utilized for the production of olive–pomace oil and pomace wood (Valta et al. 2015). In summary, the method includes: reception and storage of fresh pomace, drying of pomace, extraction of dry pomace, distillation, concentration of hexane-water, separation of hexane-water and storage of olive–pomace oil. In addition to the oil produced, exhausted pomace or pomace wood is also produced. This is an example of successful valorization of a by-product, since a waste that is produced from one company can be the raw-material for another. Olive–pomace oil producers buy pomace from olive oil producers and thus, olive oil producers are consistent with their environmental obligations and have financial benefit at the same time. Indeed, a common practice is that pomace oil producers pay olive oil producers with pomace oil or pomace wood instead of money (Valta et al. 2015).

According to the results of the CIRCOLIVE survey in Croatia, all surveyed olive growers and olive mill owners **compost wet or dry pomace** in piles and **use it as an organic fertilizer**, but only one of them uses the pomace as **biofuel**. The majority of olive growers and olive mill owners (85.7%) compost pomace for more than 12 months. Most used practice of using or disposing pomace in Portugal is **producing olive pomace oil**. The pomace produced in Italy is either sold or given away for free to pomace processing plants. Regarding Spanish olive growers and mill owners, survey results showed that mill owners prioritize the efficiency and profitability of sending pomace to extractors, whereas olive growers who are also mill owners might explore a broader spectrum of uses, likely influenced by their dual role in production and processing. Among the olive oil producers that answered the online questionnaires in Greece, the 60% use olive wet or dry pomace in their enterprises for the production of pomace oil and/or pomace wood. Although only the 20% of the respondents use it to produce biofuel, all of them agreed that it is a high-quality renewable energy source and its usage as biofuel is rather useful. Finally, the other 20% of the respondents answered that they dispose wet or dry pomace at a disposal site.

During the field research for the purpose of CIRCOLIVE project, a stakeholder in the olive growing and oil production from Croatia stated that he uses part of the pomace on its own agricultural land. After 12 to 15 months, he mixes the composted pomace with manure from organic production from other farmers and uses it as such on a third of the land area every year. Other part of the obtained pomace is further sent for processing into **energy products (pellets) from olive pomace**. Stakeholder in the business with by-products/waste from Croatia obtained pellets made of pomace and olive pruning pellets. As for the production technology of olive pomace products, the aforementioned stakeholder uses double drying, mechanical and thermal. During mechanical drying, the percentage of moisture in pomace decreases from 70% to 30%.

The obtained pellets are sold on the market as fuel.

Two of the agro-food experts/professionals that were interviewed during field research in Greece own/work in olive waste treatment plants that mainly process pomace (wet or dry) for the production of value-added products. Specifically, they collect initially the first oil produced by the mechanical treatment of the pomace (in Greek called "repasolado") as its value in the Greek market is higher than olive pomace oil. At this stage the product is being dried in order to reduce its moisture, through the addition of dried air into the driers. Moisture is then expelled through chimneys in the form of steam. Afterwards the product is chemically processed in order to produce pomace oil, which weights the 5% of the pomace weight. This oil must be additionally refined in order to be edible. At the end of the procedure as a by-product **pomace wood** is also produced and **can be used as fuel**. Overall, from 100 kg pomace, approximately 5 kg of olive pomace oil and 50 kg of pomace wood are produced. The first oil ("repasolado") as well as the olive pomace oil are sold at an indicative price of 5€/kg and 2.5-3€/kg respectively. On the contrary, pomace wood is mainly used by the enterprises themselves as a fuel for their burners and driers or is sold to neighboring industrial units or used for domestic purpose (for heating) at the indicative price of 120-160 €/t. Finally, according to an agro-food expert interviewee from Greece who specializes in the valorization of by-products and residues from two phase olive oil mills, the residues after the extraction of olive pomace oil can be used for the cultivation of mushrooms and for composting with other agricultural waste for the production of an organic fertilizer.

6.4. Wastewater

Wastewater from the olive mill is another significant by-product, consisting of water used in the olive processing mixed with vegetable water with dissolved organic substances originating from the olive fruits. Wastewater is rich in phenols, organic acids and fats, which makes it a high pollutant if not treated appropriately (Ahmad et al., 2020). Its chemical composition depends on the fruit maturity, the cultivar (Justino et al., 2010), the climatic conditions, and the method of extraction of olive oil (Khdair and Abu-Rumman, 2017). On average, wastewater contains about 5% organic substances, 1.3% oil, 1.5% sugar, 1.1% higher alcohols, 0.6% polyphenols, 0.3% pectin and impurities, and 0.3% nitrogen compounds (Žužić, 2008). The average ratio of the generated wastewater (kg) per olives processed (kg) is greater for three-phase systems (up to 1.23) than that for two-phase systems (up to 0.22) (Valta et al., 2015).

The practice of discharging wastewater into natural waterways or its direct application to land can lead to soil and water pollution, affecting local ecosystems (Akhtar et al., 2021). In many European countries, it is forbidden to discharge olive mill wastewater into the environment as there are legal regulations for the proper disposal and use of these wastewater obtained from the production of olive oil. Due to its high content of phenolic compounds, wastewater is toxic to aquatic fauna and flora and can contaminate groundwater if not properly managed. Effective treatment of this waste is therefore essential to avoid environmental degradation and guarantee the sustainability of olive oil production. It can, thereby be claimed that by uncontrollable disposal of wastewater for a long time and lack of the appropriate preservation standards and monitoring, the physicochemical parameters of the nearby ecosystems, may be altered causing permanent degradation and threatening the environmental sustainability of the region (Kounani et al., 2023).

According to recent data of the Ministry Environment and Energy in Greece (https://wfdver.ypeka.gr/el/consultation-gr/2revision-consultation-gr/) wastes derived from the oil production process in Peloponnese exhibit BOD_5 of 2,200 kg/m^3, total suspended solids up to 0,800 kg/m^3, total nitrogen up to 0,040 kg/m^{3}and total phosphorus up to 0,020 kg/m^3. Moreover, phenols up to 580 mg/m^3 are detected, as well as Cu, Zn and Cl_2 at concentrations of 297, 76 and 40 mg/m^3, respectively. These estimations are based on Hellenic Statistic Authority data (ELSTAT, 2019) and on the following assumptions as well:

- 1000 kg of olive fruits lead to the production of 200kg of olive oil.
- At a three-phase oil production system 960 L of water are required per 1000 kg of olive fruits (including the water used for the rinsing of the fruits and the centrifugation process).
- Two-phase centrifugation systems require 110 L of water/1000 kg olives (mainly for the fruits' rinsing).

The reuse of wastewater is a sustainable strategy involves recycling wastewater for other processes within the mill. This can include reusing the water for washing olives, in cooling systems, or even in the extraction of the oil itself, after filtering and appropriate treatment. Although the practice of reusing wastewater in irrigation is restricted due to the toxicity of wastewater, some technological innovations mean that, after treatment, this water can be applied in a controlled manner to agricultural crops. This reduces the need for fresh water and can help manage water scarcity. Moreover, in order to minimizing environmental impact of wastewater evaporation ponds could be used. It represents large open basins that contain the wastewater and allow the water to evaporate naturally over time, concentrating the solids and contaminants at the bottom. With the heat, the water evaporates, significantly reducing the volume of liquid effluent that needs treatment or final disposal.

Study conducted at the University of Granada in Spain, in 2014 led to a regulation allowing the discharge of wastewater from olive mills as a fertilizer, provided it is applied at a dose of 500 m³ per hectare per year and on farms located away from municipal boundaries and watercourses (Gil García, 1999). More recently, research from the University of Córdoba has proposed, using industry effluents, to reduce their environmental impact and compensate for the decline in rainfall (El Mundo, 2024).

According to survey results as part of the CIRCOLIVE project similar practices regarding the disposal of wastewater were found in all Spain, Italy, Greece, Portugal and Croatia.

In all inviestigated countries, respondents belong to categories 'olive growers' and 'olive mill owners' mainly **use purification with reusage or releasement into the environment as ways of using wastewater from the olive mill**, except Portuguese respondents which do not use wastewater recycling directly in olive processing possibly due to the technological difficulties and lack of adequate infrastructure for the efficient reuse of this resource. Moreover, Italian respondents who have access to a 3-phase decanter use the wastewater for agronomic purposes after purification. Those who have access to a 2-phase decanter, send the wet pomace, which is rich in wastewater, to biogas plants for energy production. Analysis in Spain suggests that 'olive mill owners' are more likely to implement **recycling and reuse practices** within their processes, while 'olive growers and olive mill owners' are more focused on **purification and environmental release**, indicating different priorities or resource allocations between the two groups. Concerning its reusage through the olive oil production procedure most of the respondents from Greece agreed that it contributes to the reduction of fresh water consumption, leading thus to decrease of the total olive processing costs and the negative impact of olive processing on the environment.

6.5. Other residues

Among the solid wastes originating from the olive sector also are: damaged olives, the ash from the operation of burners, the dust due to burners operation or due to drying of pomace and the sludge derived from the evaporation, the precipitation and/or septic tanks. According to the Junta de Andalucia in Spain, the by-products of the olive agro-industries have a wide variety of uses. These uses include animal feed, direct incorporation into the soil, composting, and bioenergy production (Junta de Andalucía, 2023).

Table olive industry generates significant amounts of wastewater annually derived through the alkaline treatment, fermentation, and washing steps of the olives, since olive fruits cannot be consumed directly once collected due to their bitter taste. These wastewaters are characterized by high conductivity and salt content, as well as high organic and biophenol content and due to their composition, they can pose a worldwide threat to the environment (Huertas-Alonso et al., 2022). In Greece, olives are usually, after being collected, placed directly in brine and left there for months in order for their bitterness to be completely removed. By this treatment the level of pollution caused is smaller and the final products are in full agreement with the trend of consuming as least treated products as possible. The production of preserved table olives has not been developed in Croatia (Gugić et al., 2010), and therefore the residues of table olive production do not represent significant quantities in the relatively small production of Croatia.

Pomace oil can be generated from pomace during process carried out in extractors or pomace oil plants. By-products generated in these agro-industries depends on the type of extractor and the extraction processes used (physical and/or chemical). Pomace oil is not sold directly to consumers in Portugal, but is mostly exported to the Spanish market for the purposes of industrial frying and even sold to the general public as a low-quality fat. In Greece, in olive pomace oil industries, dust is usually collected in cyclones and comes from the dryers of pomace and from steam boilers. Dust originated from dryers is being initially extracted and then burned along with pomace wood in dryer burners or steam boilers, while dust from steam boilers is burned with pomace wood.

Lampante olive oil is an oil of impaired quality that is not intended for consumption and should be refined. In recent years many olive mills in Portugal have installed what is known as a lampante line, removing the remaining percentage of oil from the olive pomace, which means that pomace extraction companies have less chance of obtaining pomace oil. The mills thus start to obtain lampante olive oil, which does not fulfil certain internationally defined quality parameters, and sell it to the olive oil refining industry, which is another source of income. Together with the sale of olive pits, the mills thus acquire two additional sources of income. In contrast, quantities of olive oil of the lampante category in terms of olive production residues are negligible in Italy and Croatia.

In addition, the mills in Portugal also use another by-product, **sediment material from oil storage tanks**, which is deposited at the bottom of the vats containing tens of thousands of liters of olive oil and is used to make soap in the cosmetics sector and to produce candles. Greece also found its usage in soap manufacturing industries.

In Greece, the **sludge resulting from the treatment of wastewater** is collected, dehydrated and used, most of the time (83%) as a soil improver.

7

Sustainability and Environmental Impact

7. Sustainability and Environmental Impact

This chapter reports some of the most common sustainable practices in olive growing and olive oil production found during desk research for the purpose of CIRCOLIVE project. It reflects the development of the production sectors, agricultural machinery, industrial machinery, and the commitment to new technologies and innovation, which are essential for implementing the principles of the circular economy and improving environmental sustainability.

One of the primary aspects of sustainability in olive growing is the **adoption of ecological farming practices.** Organic olive farming avoids the use of synthetic fertilizers and pesticides, which can lead to soil degradation, water pollution and loss of biodiversity (Pleguezuelo et al., 2018). An increasing number of olive growers are switching to organic farming, stimulated by environmental awareness and the growing demand for organic products on the market (Perpar and Udovč, 2019). Organic farming practices also promote soil health through the use of natural composts and crop rotation, which helps maintain soil fertility and structure.

Water management is another key element of sustainable olive growing. Olive trees are naturally drought tolerant, but climate change has brought erratic rainfall patterns, making more efficient use of water even more important. Drip systems, which deliver water directly to the roots of the trees, are increasingly being used in olive groves. This method minimizes water wastage and ensures that the trees receive the optimal amount of moisture, reducing the overall water footprint of olive growing.

Preservation of biodiversity is also an integral part of sustainable olive growing (Marino et al., 2019). Traditional olive groves, often interspersed with wild plants and animals, support rich biodiversity. Olive growers are encouraged to preserve these traditional practices, which help maintain ecological balance and increase the resistance of olive trees to pests and diseases. Furthermore, integrating cover crops, such as legumes, into olive groves can improve soil health, prevent erosion, and provide habitats for beneficial insects.

In the production process, sustainability efforts are focused on energy efficiency, waste management and reduction of greenhouse gas emissions (Gkisakis et al., 2020). Many olive mills invest in **energy-efficient technologies**, such as modern presses and centrifuges, which reduce energy consumption during oil extraction. The use of renewable energy sources, such as solar panels, is also becoming increasingly popular to power olive mills, further reducing the sector's carbon footprint.

Waste management is a significant challenge in olive oil production, but it also provides opportunities for sustainable practices. Olive pomace and vegetable water, the main by-products, can be reused instead of being disposed of as waste (Valta et al., 2015). Innovative methods such as composting olive pomace for use as a soil improver or its use in biogas production are slowly starting to be implemented. In addition, advanced plant water treatment technologies, including anaerobic digestion and phytoremediation, could help **reduce its environmental impact and enable recovery of valuable resources** (Agrahari and Kumar, 2024).

7.1. Sustainable Practices in Olive Farming and Olive Oil Producing

Like all industries, the agri-food industry for olive oil produces a range of waste that must be managed to prevent contamination. Challenges such as water availability, sustainable food production, and climate change mitigation can be addressed within the framework of such strategies. Olive oil production generates a wide variety and amount of waste and by-products that must be managed properly in compliance with current legislation to ensure environmental protection and conservation (https://ecoprolive.com/).

At the same time, it is possible to consider alternatives that create new business opportunities for olive growers under the bioeconomy paradigm. This approach aims to optimize the use of resources, materials, and products, maintaining their value in the economy for as long as possible and ultimately minimizing the final generation of waste. In this sense, many of the previously misnamed "wastes" become by-products or new raw materials, transforming problems into opportunities.

From the aspect of wastes' valorization olive mill wastewater could be utilized either as a substrate for the growth of microorganisms (e.g. oleaginous yeasts, edible fungi) that will lead to the production of fertilizers, bioproducts and/or animal feed, or as a cheap source for the recovery of compounds like phenols (e.g., hydroxytyrosol, oleuropein, phenolic acids, tannins, flavonols, anthocyanins, etc.) and dietary fiber (e.g., pectin). Phenols have been reported to present several biological activities such as antioxidant, free radical scavenging, anti-inflammatory, anticarcinogenic, and antimicrobial activities, while dietary fiber are currently used as additives in food products due to their ability to provide advanced technological properties and health claims to the final product (Souilem et al., 2017). The valorization of olive mill wastewater for dyeing textile materials, such as wool and acrylic fibers, has also been proposed as they constitute an abundant source of natural dyeing substances. Furthermore, olive mill wastewater due to its substantial sugar, volatile acid, polyalcohol and fat content may be utilized as a substrate for biohydrogen, biomethane and bioethanol production (Valta et al., 2015). Among the various different treatment processes for wastewater, except for lagooning or direct watering on fields, are co-composting, physicochemical methods, ultrafiltration/reverse osmosis, chemical and electrochemical treatments and manufacture into animal foods (Rahmanian et al., 2014). By categorizing the proposed techniques three categories are denoted: (1) reduction of the wastes by converting oil production systems from three phase to two phase continuous systems; (2) reduced impact of the polluting load to the recipient via detoxification methodologies and (3) recovery or recycling of components from olive mill wastes. A sustainability and benchmarking study of olive mill wastewater treatment methods, claimed that the most effective processes in terms of organics reduction are membrane filtration, electrolysis, supercritical water oxidation, and photo-Fenton. Anaerobic digestion, coagulation, and lime processes had the lowest environmental impact, while composting and membrane filtration were the lowest-cost methods, owing to the added-value of composts and phenolic compounds, respectively (Zagklis et al., 2013).

In Spain, mills are increasingly focused on optimizing both water and energy resources. New machinery being installed in the extraction process uses water more rationally and controlled, as water is an increasingly scarce resource. This includes not only its consumption but also the discharge of that water, which previously ended up in evaporation ponds. The installation of more efficient motors in machinery is leading to a reduction in energy consumption, allowing mills to gradually adapt to the new scenario of fighting climate change (El Mundo, 2024). Most of the technology is used for less consumption of water. The sector is using modern machinery that is increasingly efficient and consumes less water, using only 1 L of water for every 100 kg of olives processed. But not only are measures being taken in oil extraction to mitigate climate change, but also in the use of by-products generated by the mill. These include using olive pits as biofuel (once treated and certified) and pomace (a less valued by-product) primarily as compost. Using compost as a soil improver in many crops leads to enhanced yields. This approach helps close a circular economy around olive farming (https://smallops.com/, 2022).

From the information gathered during this research, we can conclude that there are increasingly environmentally sustainable practices that enable olive oil producers to earn a higher income by incorporating all the by-products and waste from the olive groves and mills into their holdings. Some of the main sustainable practices adopted include efficient irrigation and water management; use of resilient olive varieties (reduces the need for irrigation and increases the resilience of olive groves); adoption of practices such as tilling and mulching, which helps maintain soil moisture and reduces erosion and improves soil quality; energy production from by-products and reusage of wastewater from olive oil extraction units.

In conclusion, sustainable practices in olive growing and olive oil production are key to minimizing the environmental impact of the olive industry. **By adopting ecological agriculture, efficient water use, energy-efficient technologies and effective waste management strategies, we can ensure that olive oil production remains environmentally responsible and economically viable for future generations**.

8

State of Circular Business Practices in the Olive Sector

8. State of Circular Business Practices in the Olive Sector

The growing volume of olive production is leading to a parallel rise in organic residues, particularly from olive pruning and the processing of olive fruit. While certain sustainable practices are already in place within the olive sector, the increasing quantity of organic waste necessitates broader adoption of innovative management strategies. These strategies should align with circular economy principles, focusing on transforming biomass waste into valuable resources, reducing environmental impact, and enhancing sustainability across the olive production lifecycle. Expanding these practices is essential to address the challenges posed by the surge in organic residues.

8.1. Trends and Preferences

The remains of organic mass from olive production can be valorized in the context of the circular economy, which, in the green transition strategy, is one of the key topics of the common agricultural policy of the European Union. For example, more than 500,000 Italians have a job related to circular economy, which confirms the importance of this approach within the supply chain, including the olive sector (Ncube et al., 2022).

When it comes to disposing of pruning residues in olive growing, the most common way of disposing was to remove them from the plantations and burn, with the resulting ash, which contains valuable minerals and nutrients, usually not being returned to the plantations. However, recently, the shredding of these residues in the plantation itself has been increasingly applied, which is a consequence of the increasingly better equipment of farms with heavy mulchers, as well as state subsidies that encourage weeding and mulching of inter-row areas in perennial plantations. Olive pomace, the most abundant solid by-product in olive oil production, nowadays is mainly used to extract pomace oil and the cake residue is destined to energy production (Ncube et al., 2022). In addition, solid residues are also widely used as feedstock, being one of the fields in which it is possible to create new value from biomass (Raimondo et al., 2021). Wet pomace is also used as fertilizer by being spread on farmlands. However, such practice must be compliant with the geological, pedological and hydrologic conditions of the site (Stempfle et al., 2022). Also, an increasing number of olive mills are installing equipment for extracting pits from pomace, which is then used as a very valuable, energy-rich fuel.

Recent research studies have revealed opportunities to recover valuable compounds, such as specific polyphenols, phenols, proteins, fats, cellulose and lignin, from olive sector's waste (Madureira et al., 2022; Carmona et al., 2023). By ways based on the circular economy and its principles, olive waste can be converted into new and higher value-added products, such as biofertilizers, bioenergy, purified water, biobased materials, food and feed additives (Kounani et al., 2023). Following the example of biogas production from livestock waste, anaerobic digestion technology is now emerging as a solution for managing the olive mill wastewater in Greece. In northern

Greece for example, a group of olive oil producers are disposing of the toxic material while contributing to the production of green energy via the first biogas plants that process liquid waste produced through olive oil extraction. Biogas plants are being built all over Greece, spreading thus the word and promoting the model of circular economy. However, there are still some challenges involving the low quantities of olive mill wastewater currently feeding the biogas plants in relation to the total amount produced across the country and the seasonal flow of raw material as well. The latest problem could be solved by potentially storing the waste in the premises of the biogas unit to feed supply through the year, but this means that appropriate storage should have been planned during the design of the biogas plant facilities.

According to the survey conducted for the purpose of CIRCOLIVE project, certain trends and preferences were found.

When asked about the **motives for mulching pruning residues**, respondents mainly expressed 'Availability of technologies, knowledge and experience', 'Lower costs and/or higher revenue' and 'Awareness of sustainability' as key drivers in Spain, Italy, Greece, Portugal and Croatia. In general, 'Awareness of sustainability' stands out as the most expressed motive in most of the mentioned ways of dealing with pruning residues among the respondents. Overall, mulching pruning residues is widely recognized for improving soil health and significantly reducing soil erosion, with additional benefits including the addition of organic matter and the promotion of microbial activity. Opinions on its effectiveness in increasing soil organic carbon content and water infiltration vary.

Regarding the **motives for using pruning residues**, majority of Italian respondents do not employ practices related to the use of pruning residues, those who do primarily cite sustainability awareness as the main reason for mulching. Additional motivations include cost-effectiveness and increased revenue from composting, as well as the production of pellets and firewood. Legal obligations and support also play a crucial role in their decision-making. In Spain, primary reasons for utilizing pruning residues as by-products among 'olive growers and olive mill owners' revolve around cost reduction, income generation, and heightened awareness of sustainability. Legal obligations and support, alongside technology, knowledge, and available experience, also play crucial roles in their decision-making. For 'olive growers' in Spain, reducing costs and increasing income and awareness of sustainability are strong drivers, alongside legal obligations and the availability of technology and knowledge. Spanish respondents mostly selected the option 'Not applicable' regarding the reasons for using pruning residues for pellet production, livestock nutrition and the use in the pharmaceutical and food industries.

Regarding **the controlled burning of pruning residues**, respondents from Italy were more likely to disagree with the statement that it is ineffective due to the loss of valuable organic material. Many Spanish respondents find it as a quick way to dispose of waste and believe it provides necessary nutrients back to the soil yet expressed their concerns about pollution and the danger of wildfires with high disagreement rates on its usefulness and safety.

Composting is recognized for its contributions to soil health and waste reduction, though there are some concerns about its labour-intensive nature and potential costs. The majority of respondents from Croatia agree that composting pruning residues reduces organic waste in landfills, and they also perceive the obtained compost as a quality organic fertilizer. Spanish respondents largely had a neutral perspective regarding the advantages and disadvantages of olive pomace composting. Significant number of respondents in Croatia and Spain agree that the compost from pruning residues improves the structure of the soil and reduces the need for chemical fertilizers. Portuguese respondents expressed the disadvantage of slow decomposing of olive pomace. Spanish respondents largely had a neutral perspective regarding the advantages and disadvantages of olive pomace composting. However, there is notable support for specific statements, such as 'The best available way to use olive pomace is composting' and 'Due to the low content of organic acids and phytotoxins, amending soil with olive pomace compost does not pose an environmental risk'.

Regarding the **usage of pellets made from olive by-products**, in all investigated countries, majority of respondents see the advantage of pellets in their high energy value.

The use of olive pits as an energy source in Spain and Portugal is largely seen as positive, for providing natural energy and being renewable, with some respondents highlighting the minimal processing required and the potential for heating and power generation. Situation in Italy varies, with some statements receiving high levels of agreement while others see significant disagreement, highlighting ongoing technological gaps and the need for improved practices (Figure 19 in D2.2 Italy, 2024).

Among Greek respondents, there is a general belief that there should be financial support from the government towards circular economy practices, improvement of the legal framework and greater awareness of all those who are involved in new circular practices. A significant problem that has to be solved is mill owners' frequent resistance to change, maintaining the understandable rationale they have been using for hundreds of years, highlighting thus, some difficulties to adopting new technologies.

Overall, respondents' preferences lean strongly towards sustainable practices such as mulching and composting, motivated by economic gains and environmental consciousness, while also acknowledging the practical benefits and challenges associated with burning residues. Overall, economic and technological reasons seem to drive decisions in certain categories, while others are considered less relevant.

8.2. Technological Gaps in the Implementation of Circular Practices in the Olive Oil Sector

The **technological gaps** in implementation in the olive sector are mainly related to a **lack of suitable infrastructure, insufficient technical knowledge, legislation and low digitalization**, especially among small producers. Despite the progress made, several barriers to implementing circular economy practices in the olive oil sector remain.

To overcome these shortcomings, a coordinated effort between the public and private sectors is needed, focusing on technical support, investment in infrastructure and ongoing training for producers to ensure an effective transition to the circular economy in the olive sector, as well as a better understanding and/or rectification of current legislation. Despite the motivations addressed in previous chapter, significant technological gaps and challenges hinder the effective implementation of circular practices, particularly in terms of scalable and cost-effective methods for converting these materials into high-added-value products.

The implementation of circular practices, such as the valorization of by-products and the treatment of wastewater, still encounters many obstacles due to the lack of accessible technology and the resistance to change of various stakeholders in the sector. To overcome these shortcomings, a coordinated effort between the public and private sector is needed, focusing on technical support, investment in infrastructure and ongoing training for producers to ensure an effective transition to the circular economy in the olive sector, as well as a better understanding and/or rectification of current legislation.

From **the CIRCOLIVE interviews** with relevant stakeholders in the olive oil industry from Portugal emerged that **the technological gaps** in implementation of circular practices in the olive sector are mainly related to a lack of suitable infrastructure, insufficient technical knowledge, legislation and low digitalization, especially among small producers. To overcome these shortcomings, a coordinated effort between the public and private sectors is needed, focusing on technical support, investment in infrastructure and ongoing training for producers to ensure an effective transition to the circular economy in the olive sector, as well as a better understanding and/or rectification of current legislation. Huge concern for interviewees is limited access to technology, lack of technical knowledge and non-profitability of innovative practices. Furthermore, interviewees from Greece highlighted the gaps in existing legal framework, the lack of technological assistance and knowledge, as well as limited financial support from the government that discourage the professionals of the sector to effectively implement more sustainable practices. Speaker in Spain emphasized that the collaboration between different links in the value chain is crucial, the collaborative economy and sustainability are not always fully integrated into business practices, which could be a shortcoming in the sector. Italian interviewees highlighted the lack of adequate space in agricultural enterprises/olive mills for constructing extraction plants and the absence of skilled personnel capable of operating such equipment. Croatian interviewees said that legislation is not fully regulated in the sector of by-products/waste from olives, and as a result there is ambiguity in the handling of certain residues and by-products from olives. Insufficient financial support for innovative projects, as well as the problem of assistance in the construction of basic infrastructure/facilities for the processing of olive by-products/waste, were also identified as potential weaknesses and obstacles.

Analysis of the CIRCOLIVE survey results about **disadvantages of certain ways of dealing with pruning residues** concluded that the key obstacles to mulching include a lack of technology or expertise. Regarding significant composting barriers, in Italy include not only technological or knowledge gaps but also legal restrictions and inadequate support for implementation. These technological challenges, combined with regulatory constraints, impact the efficiency and feasibility of composting practices. In Croatia, olive growers identified composting as a demanding process that requires knowledge. Furthermore, there is no organized system for composting in the field, the composting process is long and requires a large space, and inappropriate composting can result in the spread of diseases in plantations. A significant barrier in Greece is the lack of technology and knowledge needed to implement advanced practices such as composting and controlled burning. This gap prevents many producers from adopting these methods, which could otherwise contribute to more sustainable farming practices. There is a notable perception among some respondents that the environmental benefits of these practices are not significant enough to justify the costs and efforts. This perception could further hinder the widespread adoption of circular practices in residue management.

Results about **pellet production barriers** indicate that the technological solutions are not fully optimized or well-supported. As **disadvantages of olive pomace composting** in Croatia, the majority of respondents state that the pomace decomposes slowly, that composting takes at least 12 months, and that the legal regulations for the use of olive pomace compost in agriculture are complex.

Although the **use of olive pits and pomace to produce biomass and biofuels** has shown great potential, the adoption of these technologies **is still limited**, and the lack of understanding of how to classify pits as waste or by-products means that the sector has difficulty disposing of pits properly. The main gap, according to Portuguese respondents, lies in the lack of technical knowledge and the absence of specific equipment to efficiently transform these by-products into energy. This scenario is particularly challenging for small olive producers, who don't have enough scale to justify the necessary investments in energy generation equipment. In Portugal, many producers still rely on conventional solutions, such as simply applying waste to the soil without proper treatment or monitoring. Although practices such as applying wastewater to the soil can be a viable solution, the lack of dilution and monitoring technologies makes this practice risky for the environment.

Another weakness noticed in Portugal is the **low level of digitalization in the sector**, specifically with regard to effective monitoring of waste flows and their recovery. Digital technologies, such as sensors for monitoring soil quality and the efficiency of composting processes, are essentially used by large producers. The lack of digitalized management of circular processes prevents the optimization and efficient use of resources, compromising the implementation of sustainable practices.

Spanish 'olive growers' consider the **barriers to implementing circular business practices** as lack of social and environmental awareness, legal restriction and insufficient support along with the lack of technology and knowledge. These barriers indicate that while producers might be willing to adopt more sustainable practices, the financial and educational resources required are not sufficiently available. 'Olive growers and olive mill owners' from Spain also see the similar barriers while highlighting the need for better regulatory frameworks and support systems to facilitate the adoption of sustainable practices. Both groups identify legal obligations and support as less significant motivators compared to other factors like reducing costs and increasing income, or awareness of sustainability. This indicates a possible gap in policy effectiveness or support mechanisms that are not sufficiently encouraging these sustainable practices. The perception of technology, knowledge, and available experiences being moderate to low suggests that there is room for improvement in providing the necessary tools and education to make these practices more accessible and feasible.

The technological gaps, coupled with regulatory challenges and the need for increased training and collaboration, continue to present significant hurdles for advancing circular economy practices in the olive oil sector. The availability of technology, knowledge, and expertise is crucial for the adoption of more advanced residue treatment methods such as composting and pellet production.

8.3. Best Practices of the Implementation of Circular Practices in the Olive Oil Sector

This sub-chapter examines **best practices for implementing circular economy principles in the olive sector**, highlighting strategies such as **waste reduction, by-product valorization, resource recycling, and sustainable energy use**, which are transforming the industry into a more environmentally friendly and economically efficient model.

According to Greece desk research, following best practices for implementing circular economy principles in the olive sector could be introduced. Concerning the olive growers, including valorization of waste and by-product strategies, such as valorizing olive tree pruning biomass directly in the olive plantation for compost or (in moderation) as animal feed, would be a very good practice in terms of circular economy. Furthermore, they could also collect leaves and dry them for herbal infusions (highly appreciated as antioxidants) as an upcycling opportunity. Olive mill owners in turn should seriously consider a change for more advanced technological solutions concerning their mills (two-phase systems) that will lead to fewer wastewater or olive cake amounts. Olive pomace should continue to be used for the extraction of olive pomace oil, which can be offered to food industry customers or for the production of traditional soaps and pomace wood as well. Also, enterprises that specialize in olive oil waste valorization should be mainly recommended to develop partnerships with research institutes in order to make their innovative ideas applicable or upscale their technological solutions. It is also crucial to raise both producers and consumers awareness by notifying and underlying the importance of circular economy principles, leading their behaviors on more sustainable paths.

An example of the good practice of applying the circular economy in olive growing in Croatia is the biowaste management model implemented by the utility company Ponikve in the city of Krk. The model is based on the collection of all pomace that remains after processing olives in all olive mills on the island of Krk, as well as branches and other pruning residues. They are mixed with green and bio waste from the household and everything is composted together (http://www.ponikve.hr/). Separation of olive pits during olive oil processing is carried out by several olive mills in Croatia. The pits are separated from the pomace of olives, after processing the fruits into olive oil. Olive pits are a very valuable fuel that can be used for heating buildings, since their energy value is about 30% higher than wood pellets. At the same time, the price of 1 ton of olive pits is 270-300 euros, which is 50% cheaper than the price of wood pellets (https://baustela.hr/odrziva-gradnja/grijanje-na-kostice-od-masline-duplo-jeftinije -from-pellets-and-more-and-more-popular/). Respondents from Portugal also take advantage of pits' high caloric value and use them as a source of energy. During the primary research in Croatia, it was determined that the selected survey respondents also apply certain sustainable practices in the olive growing sector. Pruning residues are mostly disposed of by mulching or used for firewood, composting and pelletizing of pruning residues is carried out. Wastewater is mostly treated and reused for irrigation. From interviews conducted with a stakeholder in the business with olive by-products/waste, it was established that the stakeholder produces pellets from pomace and pellets from olive pruning. On an annual level, 3 to 5 thousand tons of pellets are produced, which is the largest possible production with the current capacity of the plant, and states that certain legal and financial restrictions prevent the expansion of this plant in order to be able to process all available pomace in the area of its plant.

In addition to valorizing by-products, mills in Portugal are investing in energy efficiency as part of good circularity practices, in particular - renewable energy (many mills are integrating solar energy to power their operations, reducing dependence on non-renewable energy sources and carbon emissions) and efficient extraction technologies (the use of more efficient technologies for olive oil extraction, such as the two-phase system, has made it possible to reduce the volume of wastewater generated and, at the same time, increase production efficiency). Desk research revealed several other good practices in Portugal e.g. several large mills in Portugal are studying technological solutions that will allow them to stop sending 'wet' pomace to the pomace dryers and extract the maximum revenue from it in facilities adjacent to the mills. Other similar discoveries like URSA Project, whose main objective is to increase the soil's organic matter content by incorporating compost resulting from agricultural by-products from different producers can be found in a table from chapter 8.2. in D2.1 Portugal, 2024.

Analysis of the questionnaire revealed that Italian olive growers and olive mill owners' best practices include utilizing available technology and expertise to enhance the effectiveness of mulching; adhering to guidelines that address both the technological and legal aspects of composting, ensuring that it is both feasible and environmentally beneficial; improving the technology used for pellet production and managing the production process to balance cost and energy consumption, thereby maximizing the benefits of this approach; and implementation of advanced burning technologies and practices that minimize material loss can enhance the effectiveness of this method.

In Spain, the extraction and utilization of polyphenols from olive mill wastewater have garnered attention due to their potential applications in the pharmaceutical, cosmetic, and food industries. For instance, studies have shown that polyphenols extracted from olive mill wastewater can enhance the nutritional quality and shelf life of olive oil without altering its organoleptic properties. This extraction process not only adds value to what would otherwise be waste but also aligns with circular economy principles by reducing environmental pollution and promoting sustainability (Tundis et al., 2022). According to different sources, pomace in Spain is starting to be employed in other fields such as for electric power generation (https://www.oliveoiltimes.com/, https://ecomercioagrario.com/). Including wet pomace or dry pomace in animal feed is not new, but its use should be increased in the future as pig diets.

9

Technological Advancements

9. Technological Advancements

The following chapter explores the technological advancements and innovations that are reshaping the olive sector, from modernized harvesting techniques to precision farming and eco-friendly processing methods. It also delves into future technological trends, such as sustainability-driven practices, the increasing role of digitalization and the integration of AI and automation, all aimed at enhancing production efficiency, improving oil quality, and addressing the environmental challenges facing the industry.

9.1. Innovations in Production and Processing

Treatment and disposal of olive pomace and olive mill wastewater represents one of the main problems faced by industries involved in the production of olive oil. Raw olive mill waste and by-products are potentially phytotoxic due to the presence of polyphenols, lipids and organic acids, making its disposal a major environmental problem in the Mediterranean countries. On the other hand, it also contains high content of organic matter and plant nutrients that could be recovered as fertilizers to sustain yield production. Further, both olive pomace and olive mill wastewater are also a valuable source of value-added raw chemicals (e.g. hydroxytyrosol, vitamin E, fatty acids, various antioxidants, etc.) that can be further used in pharmaceutical or chemical industry. Additionally, the recovery of biomass-derived by-products, such as olive leaves, has significant potential to become an alternative for natural additives in food production.

Olive oil by-products can be used in different ways improving the sustainability of oil production. Pruning residues consist of branches, which could be used as biomass for fuel production (Intini et al., 2014), and leaves, which could be useful for phenolic compound extraction (Cerri et al., 2024) or animal feeding. For example, in Italy, Mattioli et al. (2018) used selenium-fortified olive leaves as a dietary source of selenium for rabbits, demonstrating an increase of bioactive compounds content in meats. Olive mill wastewaters and pomace are also a great source of polyphenols, that can possess antioxidant and antimicrobial activity (Pannucci et al., 2019; Ricelli et al., 2020). Russo et al. (2022) proved an antibacterial activity of phenols extracted from wastewaters against clinically relevant Gram-positive and Gram-negative human pathogens but also against phytopathogens like *Pseudomonas syringae* pv. *Tomato*. Given their bioactivity, these compounds can be used as functional ingredients for the production of fortified and enriched foods, like cereal-based foods (Cedola et al., 2020).

Concerning the usage of agricultural wastes in the production of biogas in Greece, 83 licenses were issued in 2015 for biogas plants with a total capacity of 441.4 MW (Kounani et al., 2023). However, among the operating biogas plants, three are in landfills, four use agricultural waste for biogas and two generate heat in the food industry (ABI, 2018).

During desk research conducted for the CIRCOLIVE project various different project and research articles were found in the field of valorization of olive by-products in Portugal, some of which include sustainable management of phytopharmaceuticals in olive groves, sustainable use of olive pomace in an integrated recovery chain (https://morecolab.pt/inicio/projetos/projetos-olivebioextract/) valorization of ash and olive pomace and analysis of the bacterial community in different phases of olive pomace composting process (Royer et al., 2023, D2.1 Portugal, 2023).

Croatia also had many projects regarding valorization of olive waste in sustainable food innovation (https://croris.hr/projekti/projekt/116), valorization of olive waste by microbial multispecies biocatalytic aggregates (https://biocolloid.ijs.si/projects/arrs-j4-4561/) and reduction of greenhouse gas emissions through waste utilization (http://redgreenplant.iptpo.hr/). It was found that scientific articles mainly focused on olive pomace polyphenols and various techniques for its removal from olive mill wastewater (Lončarić et al., 2021), different usages of olive leaves (Repajić et al., 2018, Novoselić et al., 2023, Novoselić et al., 2021) and effect of olive-processing technology on the utilization of olive mill pomace as a soil amendment (Černe et al., 2023).

Some interesting studies conducted in Greece were about composted rice husk combined with olive pomace and leaves in comparative pilot experiments at a three-phase olive mill (Muktadirul Bari Chowdhury et al., 2014); the suitability for the cultivation of the edible mushroom *Pleurotuscitrinopileatus* of two-phase mill wastes in combination with wheat straw and olive leaves (Koutrotsios et al., 2021) and in a three-phase olive mills, a new approach to wastewater treatment for organic fertilizer production via two simple processes (Galliou et al., 2018).

Additionally, other technologies have been adopted within the sector in Spain, some of which are still in their early stages. Research centers and companies are actively working on their improvement. These technologies are described as follows:

- Advanced Extraction Technologies: Innovations in extraction methods, such as the use of advanced centrifugal separation and innovative cold-pressing techniques, have improved the efficiency and quality of olive oil production. These methods reduce the need for traditional heat-based processing, preserving the oil's delicate flavours and nutritional qualities.
- Artificial Intelligence and Automation: The integration of artificial intelligence (AI) and automated systems into olive oil production has revolutionized the industry. AI algorithms are used to monitor and control various production stages, from olive harvesting to oil extraction, optimizing processes and ensuring consistent quality. Automated systems also enhance operational efficiency by reducing human error and labour costs (Envero, 2024).
- Digital Olive Oil Monitoring: Digital technologies are transforming olive oil production through real-time monitoring and data analysis. Sensors and IoT (Internet of Things) devices track factors such as olive ripeness and oil quality,

allowing producers to make data-driven decisions and improve overall product consistency. These technologies facilitate a more precise and controlled production environment.

- Innovative Packaging Solutions: The development of sustainable and smart packaging solutions is also noteworthy. There have been reports on innovations in packaging that include features like freshness indicators and tamper-evident seals, enhancing both product safety and consumer trust.

9.2. Future Technological Trends in the Sector

Based on the studies summarized, it can be concluded that in view of valorization of olive mill waste, whether solid or liquid composting, anaerobic stabilization, biochar production, and heating can be a promising valorization approaches. It was also found that elevated levels of phenolic substances in both olive pomace and olive mill wastewater indicate for their potential use as added value raw chemicals in polymer, pharmaceutical or chemical industries. Furthermore, olive leaves can be used as a resource for natural additives, further research is needed to implement new valorization technologies to the industrial-scale application.

Nowadays the olive oil extraction is carried out with technological industrial processes (continuous or discontinuous), even though the quality and the quantity of the obtained oil are still to be optimized, producing a significant economic loss for the oil sector. A possibility for trying to solve the problem could be the exploitation of biotechnology in the olive oil industry, considering also eco-sustainability and lower environmental impact of the enzymes used (Chiacchierini et al., 2007).

It can be concluded that efforts are being made to make the most of olive oil mill waste, with composting, biochar production, the introduction of olive pomace into animal feed and heating being some examples of the various approaches that are being explored. Areas such as the pharmaceutical, chemical, polymer and even civil engineering and construction industries could play a leading role in the success of the circular economy associated with the management of waste such as olive pomace and wastewater.

Looking ahead, several other technological trends are also expected to shape the future of the olive oil industry:

Enhanced AI Integration: As AI technology continues to advance, its role in olive oil production will expand. Future AI applications may include more sophisticated predictive analytics for crop yield forecasting, disease detection, and automated quality control systems. This will further enhance production efficiency and product quality (Oleo Revista, 2023).

Blockchain for Traceability: Blockchain technology is anticipated to play a crucial role in improving traceability and transparency in the olive oil supply chain. By providing a secure and immutable record of each step in the production process, blockchain can help combat fraud, ensure product authenticity, and enhance consumer confidence (Muy Interesante, 2023).

Advanced Data Analytics: The use of big data and advanced analytics will become increasingly prevalent. Spanish company Ecoprolive is already utilizing advanced data analytics to optimize the management of olive pomace and other by-products, making the production process more efficient and sustainable (Ecoprolive, 2023).

Sustainability Innovations: Future technological trends will likely focus on further advancing sustainability in olive oil production. Innovations in water and energy management, as well as new methods for recycling and reusing by-products, will help reduce the environmental footprint of olive oil production. Technologies aimed at minimizing waste and improving resource efficiency will become standard practices (Ciudades del futuro, 2024).

Precision Agriculture: The application of precision agriculture technologies, including drones and remote sensing, will enhance olive grove management. These technologies will allow for more precise monitoring of crop health, soil conditions, and irrigation needs, leading to optimized yields and reduced resource consumption (Olimerca, 2022).

Smart Processing Facilities: The development of smart processing facilities equipped with IoT devices and real-time analytics will revolutionize how olive oil is produced (Oleo Revista, 2023).

10

Market Analysis

10. Market Analysis

Market analysis is the process of determining the viability of a new product/service on the market in order to better position it on the market. Market analysis determines the state of the market, opportunities, threats, opportunities and weaknesses that should be taken into account when placing a new product/service on the market. In the following sub-chapters, an analysis of the market of by-products and waste from olives in the olive growing sector in Spain, Italy, Greece, Portugal and Croatia was carried out.

10.1. Market Forces

According to the survey, respondents from Portugal, Italy and Spain mostly sell by-products and/or waste, but that is not the case in Greece and Croatia where only a small percentage of olive growers and olive mill owners sell their olive by-product/waste (Figure 8).

In Portugal, mostly olive pomace, olive pits and lampante olive oil are being sold. Lampante olive oil is the most well-established by-product in terms of production and commercialization in Portugal, with a positive perception of the price and potential for expansion. Olive pomace plays a big role in the sector, but still faces technological and market recognition challenges, especially in the national context. Finally, olive pits, although the smallest of the three in terms of utilization and production, have significant potential, especially for energy and biofuel production, but need more investment in marketing and technology in order to gain a foothold in the market.

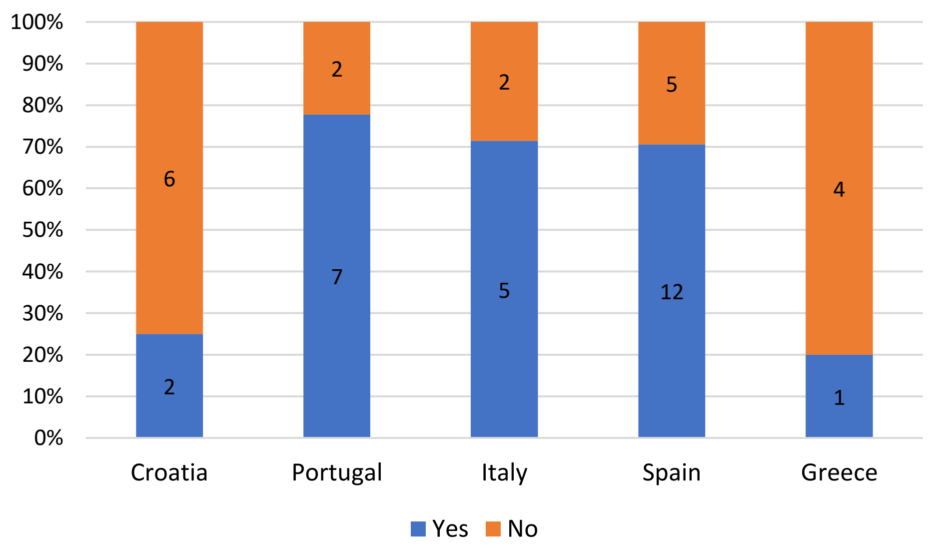


Figure 8. Sale of the olive by-products and/or waste ('Olive growers and olive mill owners' and 'Olive mill owners' categories, N=46)

It is important to mention the valorization of olive pomace in composting, which, despite being a recent development, has significant business potential. All the interviewees from Portugal emphasized the future market potential of by-products, given their ecological footprint and the fact that future market valorization cannot be based on more polluting responses than those that currently exist. As a result, the market for olive by-products and waste in Portugal is dynamic and is being shaped by various forces. Prices are influenced by supply and demand, as well as the costs of treating and valorizing waste. Distribution channels are expanding, with increasing integration of by-products into bioenergy networks, while waste is managed through local treatment solutions. The main producers and agents, such as co-operatives, technology companies and bioenergy operators, are leading the transformation of the sector, promoting sustainability and circularity in the olive production cycle.

During the investigation made for purpose of CIRCOLIVE project, three respondents from Italy stated that they sell the pomace to oil mills. These are traditional oil mills that have collaborated with olive growers and millers for generations, so there has been no competition over the purchase price of the produced pomace. One respondent reported giving away the pomace for free, but only after removing the olive pits, which are then sold separately. The last respondent mentioned giving away the pomace with olive pits to third-party companies. Those who donate the pomace for free save on management costs that would otherwise be incurred if it remained at the mill. All respondents indicated that pruning residues are reused in the field and are not sold.

Interviewees from Spain indicated that pricing for olive by-products is primarily influenced by market conditions and the prices set by refineries. Competitive pricing is essential to remain viable, especially in the energy and industrial sectors where cost efficiency is a critical factor. Recently, and due to the financial aid from the EU, more and more Spanish energy companies are setting their sights on olive oil mills. Products like biofuels and biogas are particularly attractive due to their potential to reduce carbon emissions and reliance on non-renewable energy sources. The promotion of these products leverages themes of sustainability, clean energy, and natural quality. B2B, social media and trade fairs are effective platforms for reaching target audiences. Conferences and ecological media are also important for connecting with industry professionals and eco-conscious consumers.

By-products such as pomace oil and olive pits in Greece are commonly sold in bulk to refineries and used as fuel in industrial and household settings. The rising demand for these by-products has led to significant price increases, particularly for olive pits, which is valued as an economical fuel alternative. In contrast, liquid waste from olive processing is often converted into fertilizer for local use but struggles to fully meet the needs of larger groves.

The market for by-products and waste from olives in the olive growing sector in Croatia is not sufficiently developed. Therefore, any innovative product made from olive by-products and waste is welcome. During desk-research for the purpose of CIRCOLIVE project some information on the types of products obtained from by-products/waste from olives produced and available in Croatia such as olive body scrubs, olive pomace cosmetics and olive pomace cheese was found. From the interviews conducted with a stakeholder in the business with olive by-products/waste, another good practice in Croatia was discovered. Stakeholder produces pellets from pomace and pellets from olive pruning which are then sold on the market.

It should be pointed out that newly created products represent a valuable potential for the market, especially because modern consumers are more and more environmentally oriented and focused on sustainable products. Such products generate efficient and sustainable utilization of by-products from the olive growing sector while creating new products.

The market dynamics of the olive industry reflect a growing focus on sustainability, driven by the utilization of by-products like pomace oil and pyrene wood. However, technological gaps, high costs, and regulatory challenges hinder broader adoption of circular practices. Legislative changes and increased awareness may drive further advancements, with market forces shaping the industry's approach to sustainable waste management and production practices.

10.2. SWOT Analysis

SWOT analysis is the most frequently used tool for creating a business strategy. The analysis was made in the form of a SWOT matrix, where internal factors (area of own influence) - strengths and weaknesses and external factors (which we cannot influence) - opportunities and threats are considered. It allows analysing an innovative project, taking into account every factor on which the development of the organization depends. Table 2 below summarizes findings from Spain, Italy, Greece, Portugal and Croatia. It can be concluded that similar discoveries were made in all investigating countries. Regarding **strengths**, Italy and Portugal emphasize sustainability and energy efficiency, while Greece highlights geographical advantages and zero-waste strategies. Spain and Croatia put the emphasis on the technological innovation and development of new products. When it comes to **weaknesses**, Spain highlighted the lack of vision for better utilization of olive by-products while Greece and Croatia mentioned lack of support for implementation of circular economy practices and unregulated legislation in handling olive by-products/waste. Portugal and Spain agree that high initial cost and technical shortcoming could be significant weaknesses. Regarding **opportunities**, Spain and Portugal see the benefits from external factors like EU incentives and market expansion, while Italy highlighted the promotion of circular economy measures. Greece emphasized growth in low-competition areas, and Croatia, the proximity to the EU market and potential for cross-industry expansion. Lastly, all countries agree that international competition is a significant **threat**, along with the lack of environmental awareness, lack of innovation and absence of educational training focusing on circular economy in the olive sector.

Table 2. SWOT Analysis

Strengths	Weaknesses	Opportunities	Threats
		Spain	
- Technological innovation improving efficiency and quality - High caloric and nutritional value of by-products with good preservation - Use of polyphenols - Assured demand, added value - Abundant by-product generated every year, which provides long-term returns once the olive grove is planted	- High initial investment, higher costs, lower profitability - Cyclical nature of campaigns, price volatility - Lack of a circular industry design - Sector is not highly professionalized - Producers are more interested in the main products than the by-products - Limited access to advanced technology - Atomized sector	- Technological innovation improving efficiency and quality - Opportunities in emerging markets with environmental awareness - Growing sector with significant caloric and nutritional potential in by-products - Assured demand, added value - Incentives and aids from the European Union - Political and legislative environment encourages companies to move towards more sustainable and circular practices - Public-private collaboration	- Dependence on olive availability and climate fluctuations - Variable environmental and health regulations - Social factors: lack of environmental awareness, tradition, and deficiencies in collaborative economy networks - Political-legal-institutional factors: regulatory limitations, lack of institutional support, and insecurity regarding incentives and aids - Innovation and technology challenges: obsolescence, lack of development/access to technologies, and lack of technical knowledge - Significant competition from other countries - Unfavorable weather conditions - Sudden political changes, legal adjustments, or reconstructions
		Italy	
- High Agreement on pellet production - Strong Agreement on pomace as renewable energy - Agreement on reducing fresh water consumption	- Neutral Response to composting issues - Disagreement on recycling and reuse	- Improvement in pellet production efficiency - Enhanced composting practices - Promotion of circular economy measures	- Resistance to recycling and reuse - Lack of support for circular economy incentives

Strengths	Weaknesses	Opportunities	Threats
Greece			
- Sustainability and Cost Efficiency - Local Relationships and Industry Experience - Zero-Waste Operations - Favorable Geographical Locations	- Lack of Support for Circular Economy Practices - Geographic and Regulatory Challenges - High Initial Costs and Technology Gaps	- Support for Circular Economy Initiatives - Technological Innovation for Energy Efficiency - Expanding Waste Management Services - Growth in Low-Competition Areas	- High Operational Costs and Intense Competition - Regulatory and Social Challenges
Portugal			
- Growing Sustainability - Valorization of by-product - Strong Cooperation - Favorable climatic conditions	- Lack of Treatment Infrastructure - High Initial Costs - Limited Technical Knowledge - Dependence on Traditional Techniques	- Increased Demand for Renewable Energy - Government Incentives - Expansion into new markets - Technological Innovations - Circular Economy - Climate change mitigation - Employability in the sector	- Climate Change - International Competition - Strict Environmental Regulations - Lack of Innovation on Small Farms - Market Price Volatility - Partnerships with the scientific community There are not enough olive pomace extraction companies in the region
Croatia			
- Inovative and new products - The possibility to launch a start-up in the area of circular economy - Co-financing from EU funds for starting a business related to by-products/waste	- Unexplored market potential - Unfamiliarity of production technology - Unregulated legislation in handling by-products/waste - Unequal interpretation of olive by-products/waste by different ministries, which lead to ambiguity in handling	- Proximity to the EU market - Market breadth (energy market, fertilizer market, cosmetics and pharmaceutical market, food industry…) - Absence of significant competitors on the market - Proximity to available raw olive materials (by-products/waste)	- Competition in neighboring Mediterranean countries - More advanced technologies in competing countries - Insufficiently large amount of olive by-products/waste considering the total production for entering the foreign market - Insufficient financial support from decision-makers (politicians) regarding innovative ways of reuse - Absence of educational programs exclusively focusing on the circular economy in the olive growing sector

10.3. Regulatory Challenges and Barriers

The olive by-products and waste management sector is faced with a complex array of challenges that impede its growth and innovation. Regulatory restrictions, high costs, technological gaps, and social resistance are significant barriers that need to be addressed to enable the sector to fully realize its potential in implementing sustainable practices.

Regarding Croatia, its olive by-product/waste market is still in its initial phase, and is not fully regulated. Doing business in such an environment can be challenging because the business conditions are not defined. From interviews conducted with stakeholders from the olive growing sector, the biggest challenges in dealing with by-products and waste from the olive growing sector are the undefined legislation, different interpretations of the law by individual ministries, certain restrictions on placing such products on the market, which is why the produced by-products are often reused on the olive grove, most often in the form of organic fertilizer. Also, according to the results of the conducted survey, it can be identified that there are certain legislative problems in the classification of olive pomace and its disposal in order to produce organic fertilizer and put it on the market. According to the researched situation from the available secondary literature and primary research, it is concluded that there are significant challenges and obstacles in the market of olive by-products/waste in Croatia.

The challenges and regulatory barriers in the Portuguese olive sector are multiple and complex. Compliance with environmental laws and waste management in Portugal represents a significant burden for many producers, especially smaller ones. Regulations, while necessary to protect the environment, often require high investment and specialized infrastructure, which creates a barrier to their implementation. In addition, the lack of adequate technical and financial support increases the risk of non-compliance and limits the potential of many olive growers to implement more sustainable and circular practices. Similar situation is noticed in all 5 investigated countries.

Pruning waste composting in olive growing in Portugal is a potentially beneficial practice, but it faces several significant barriers to its implementation. Concerns about the spread of disease, a lack of organized infrastructure and a lack of technical knowledge are the main difficulties pointed out by producers and mill owners. For composting to become a more common and efficient practice in the sector, it is essential to invest in education, technical training and regional composting infrastructure. With adequate support, producers can turn pruning waste into a valuable source of organic fertilizer, promoting more sustainable and resilient olive growing.

Despite the environmental benefits associated with utilizing pruning residues, most respondents from Italy do not implement related procedures. For those who do, sustainability awareness drives practices like mulching. They also cite benefits such as low costs and increased revenue from composting, as well as pellet and firewood production. However, significant regulatory challenges and barriers persist. Key obstacles to effective mulching mainly include: lack of technology and knowledge, significant initial cost, legal restrictions and insufficient regulatory and institutional support.

In Portugal, the licensing process for olive growers to be able to compost their by-products and thus fertilize the soil and the crops they grow is extensive and therefore doesn't encourage people to take a path towards sustainability. Lack of, or restrictive regulatory frameworks for the recycling and reuse of agricultural by-products and regulations regarding the environmental impact of reusing by-products can affect the practical implementation of these circular practices. Majority of respondents from Portugal agree that there is a need to raise awareness of the benefits of the circular economy in the olive sector; that the legislative framework limits the development of the circular economy in the sector; and that there is a lack of by-product transformation systems in production areas.

One of the main regulatory challenges in Spain is the strict legislation governing wastewater management. While these regulations aim to standardize by-product treatment at the regional level, they could hinder the circular economy by imposing stringent criteria and regional harmonization requirements. This may reduce the flexibility of mills to reuse or recycle waste, creating inconsistencies in implementation and limiting innovation in waste management practices. Additionally, the *Water Law* (Consolidated Water Law, Royal Legislative Decree 1/2001) imposes further obligations regarding water resource management, complicating compliance.

Many producers from Greece reported that their regions do not have established composting systems, making it difficult to implement these environmentally beneficial practices. Greek investigation concluded that financial constraints are a significant barrier to adopting sustainable practices in the olive by-products sector. High initial investment costs for processing facilities and the ongoing operational expenses are major deterrents. Many producers struggle to finance these investments, especially in the absence of adequate subsidies or financial incentives. This financial burden is further exacerbated by delays in receiving government funding, often due to broader economic crises or administrative bottlenecks. These delays force producers to rely on bank loans, increasing their financial vulnerability.

The data obtained reflects a generally positive perception of the environmental and operational advantages of turning olive pits into a source of energy in the olive sector. However, it could be said that the **main barriers are legislative, financial and**

logistical. Although producers and mill owners recognize the value of the circular economy, many are hesitant to implement these practices due to the lack of suitable infrastructure and high initial investment costs.

Similar barrier noticed in all 5 countries is the fact that **access to advanced technology is not uniformly available across the industry**, creating disparities in operational efficiency and product quality. Furthermore, there is **limited training and knowledge dissemination regarding new technologies**. This **knowledge gap prevents the industry from innovating and adopting more efficient and sustainable practices**. There is limited adoption of sustainable practices due to a **lack of awareness and understanding of the benefits of using by-products**.

11

Vocational Training (VET)

11. Vocational Training (VET)

11.1. Existing VET on Circular Business Practices in the Olive Sector

The need for more qualified people in the agricultural sector, and its growing modernization, has led to the emergence of more higher education training in the area, and in this sense, an increase in higher education graduates in the area of agriculture. Similarly, because the new paradigm of more productive, irrigated olive production has generated a set of new circumstances, investment in training professionals in the olive sector could not be ignored, both in higher education and in professional training.

During the primary research conducted in Croatia, Portugal, Italy, Greece or Spain as part of the CIRCOLIVE project on a sample of olive growers and olive mill owners it was determined that **there is no training exclusively specialized in the area of by-product and waste utilization from the olive growing sector in 5 countries**. However, **certain training programs have been established that contain parts of education aimed at using by-products and waste from the olive growing sector**, e.g. Faculty of Agriculture in Zagreb, Croatia; University of Évora, Portugal; University of Bologna, Italy; Agricultural University of Athens, Greece; University of Lleida, Spain, etc.

Outside of the academic sphere, there are also a number of **VET institutions** that offer courses on different topics in the olive sector with a small part of these courses being about circular economy approach.

In Spain, at Campus Iberus is possible to obtain a Master's degree in Circular Economy, which aims at providing advanced training in circular economy principles and practices across various industries.

In Greece, there is a special program on olive farming aiming at young farmers with duration of 150 hours. During this program, brief lectures on subjects of sustainability and circular economy are conducted, while some visits to olive groves or olive oil mills occur.

It is important to mention that Portalegre Polytechnic Institute - Elvas School of Biosciences in Portugal has recently submitted, together with Évora University, an application for a PhD in Circular Economy in Agriculture to A3ES - the Higher Education Assessment and Accreditation Agency. If this application is approved, this course will, in the 2025/2026 academic year, address circular practices in the olive sector, namely the issue of its by-products and waste. Also, the Association of Farmers of the South - ACOS, a training entity certified by the Directorate-General for Employment and Labour Relations, has indicated, through the coordinator of its training center, that it will carry out training in 2025 on the recovery of olive grove by-products, and another training course on the sustainability of olive mills, both in partnership with the Évora University.

The recognition of the importance of these skills indicates a significant potential for the future development of such courses.

The results of the survey in CIRCOLIVE project showed that only 16% of all respondents in 5 countries completed some form of course, training or education that had smaller parts of education related to the circular economy in olive growing. **Majority of respondents in Spain, Italy, Greece, Portugal and Croatia had no education in the field of circular economy** (Figure 9).

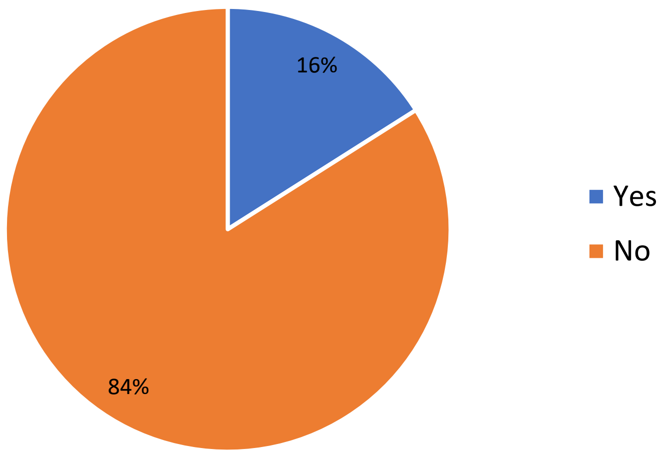


Figure 9. Data on completed courses, training and education in the circular economy in Spain, Italy, Greece, Portugal and Croatia (N=126)

During the interview in Croatia, a stakeholder in the olive growing and oil production sector stated that during his high school agricultural education and schooling at the Faculty of Agriculture in Zagreb, as part of some courses and subjects, he gained knowledge about the circular economy. The stakeholder in the business with by-products and waste from olives had no previous education and training in the area of the circular economy. In Portugal, it emerged that only one of the interviewees has training in circular practices, i.e. a postgraduate qualification in the Management of By-Products from the Olive Press.

11.2. Training Methods and Techniques, Recognition Paths/Qualification Validation Methods Used

According to the survey conducted for the purpose of CIRCOLIVE project several findings about **training methods and techniques** were found. Training and courses that respondents attended in Croatia were only a small part of the wider trainings for olive growers conducted at the Diopter Open University, as well as the program of

Mediterranean agriculture at the University of Applied Sciences of Rijeka and the lectures of the Agency for Payments in Agriculture, Fisheries and Rural Development. The educations lasted 3 to 4 months at the Open Universities, or 36 months to 5 years if it was conducted at the University of Applied Sciences of Rijeka as part of the Mediterranean Agriculture studies, but only a small part of the education was dedicated to the circular economy in the olive sector. In Italy, the courses were provided either by their regional authorities or by companies where the respondents had worked. Additionally, one respondent indicated that, as a director, he had no training in circular economy, although some of his collaborators did.

The respondents, who had some education in the field of the circular economy, from all 5 countries (Spain, Italy, Greece, Portugal and Croatia) overall stated that the educations were mostly conducted in presence (70%), and only a small part of the education was conducted online (15%) and in hybrid mode (15%) (Figure 10). This data suggests that **traditional in-person education remains the most common method**.

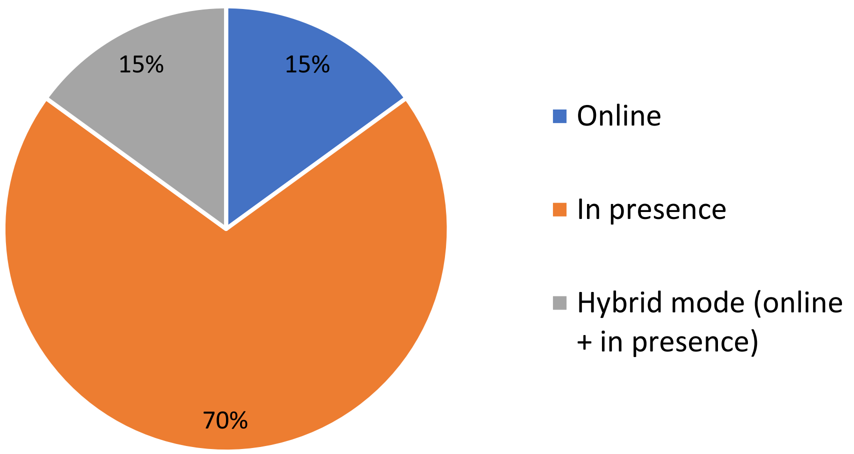


Figure 10. Method of implementation of courses, training and education in circular olive growing and/or agriculture in Spain, Italy, Greece, Portugal and Croatia (N=20)

According to the results of the primary research, **about 82% of respondents are interested in attending a course that would be exclusively dedicated to education in the area of the circular economy in the olive sector**, that is, the valorization of by-products and waste from olives (Figure 11). This suggests **a strong overall willingness to engage in educational opportunities related to sustainability**. It is important to mention that one of the Croatian interviewees expressed their interest in participating in education as an external associate or lecturer because he has a lot of experience in that area and believes that he could thus contribute to the development of the circular economy in Croatia.

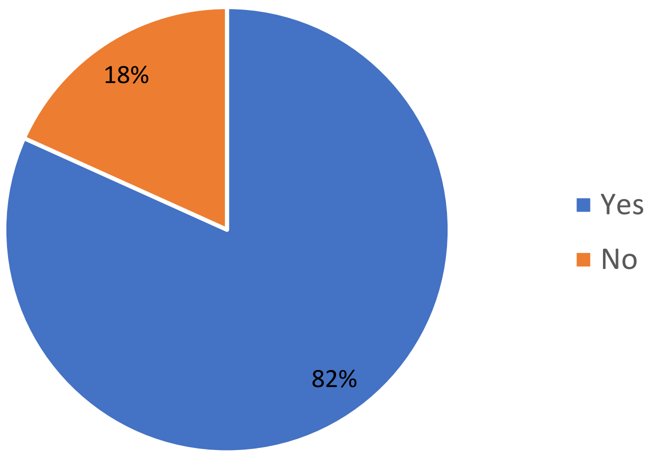


Figure 11. Expressed interest in attending a course on the valorization of olive by-products and waste in Spain, Italy, Greece, Portugal and Croatia (N=126)

In the Figure 12 it is shown that **majority of respondents would prefer online way of attending a course on the valorization of olive by-products and waste**.

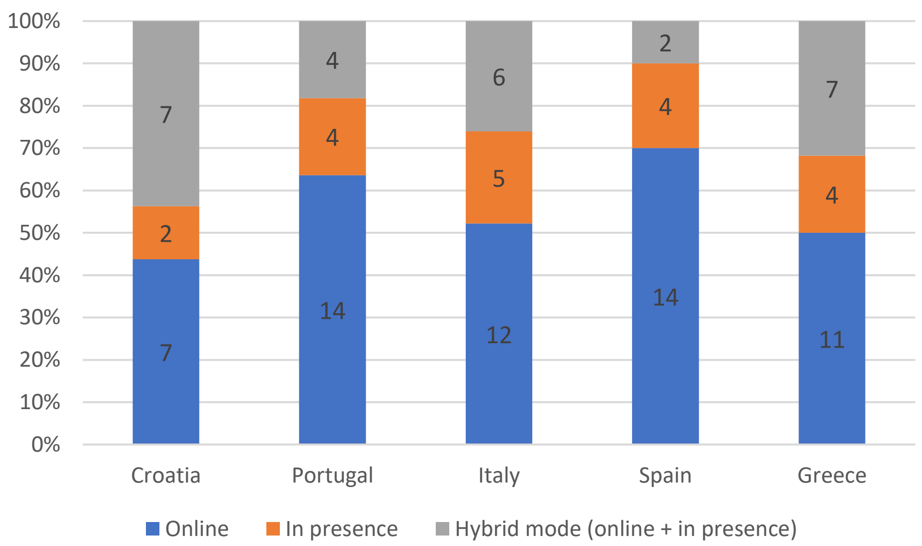


Figure 12. Preferred form of delivery of the course on the valorization of olive by-products and waste (N=103)

According to feedback from interviewed and surveyed professionals, **the most effective training approach is dual education, which combines theoretical learning with practical, field-based experiences**. This method allows students to gain hands-on experience in olive mills, thereby deepening their understanding of the production process and the operational realities of the industry. For topics related to circular economy, which are relatively new to the sector, a solid theoretical foundation is essential. However, it is equally important for students to engage in practical applications of this knowledge. This approach ensures that learners not only understand the principles of circular economy but also can implement these practices effectively in real-world scenarios. Research centres and agricultural institutions play a crucial role in bridging the gap between theoretical knowledge and practical application. They are instrumental in transferring cutting-edge research and innovations to the olive oil industry. These institutes work on various aspects of olive oil production, including the management of by-products and waste. By involving students in ongoing research and development projects, these institutions provide valuable exposure to the latest advancements in the field. Additionally, training programs benefit from collaboration with industry stakeholders to ensure that educational content remains relevant and up to date. This involvement helps to align training with current industry needs and trends, particularly in the context of sustainability and circular economy practices.

Combining face-to-face classes with online learning provides students with greater flexibility and accessibility. This blended approach is complemented by the integration of agronomic, economic, and technological skills into training programs, which is considered a best practice for preparing participants to tackle the challenges of the circular economy. Furthermore, skills are frequently validated through practical assessments, projects, and company visits, enabling students to demonstrate their abilities in real-world contexts.

11.3. Best Practices Identified Regarding the Education Programs on Circular Business Practices in the Olive Sector

Although the existence of educational programs that exclusively deal with the circular economy in the olive growing sector has not been established, certain forms of education have been found that have certain parts dedicated to this topic.

During the interviewees with stakeholders in education for the purpose of CIRCOLIVE project regarding best practices, different opinions were expressed.

Spanish interviewees agreed that an internship program focused on circular economy practices in the olive oil sector should be aimed at individuals who already have prior education in the field. Additionally, they emphasized that the program should prioritize theoretical knowledge before moving on to practical experience. The format of this training should be designed as a specialization or a master’s program, developed by a research centre or a university. Regarding the required skills, the individual responsible for developing this training should have a strong theoretical background in circular economy and, importantly, a deep understanding of the various possibilities for transforming a by-product, preferably with a focus on product technology.

In Italy, none of the interviewees expressed opinions regarding best practices in education.

During interviews in Greece, stakeholders in education expressed their support of the idea that courses on circular entrepreneurship should be incorporated into the undergraduate curriculum of Greek agronomic higher education institutes. Moreover, it is believed that the Centers of Education and Lifelong Learning of the Universities should offer relative, shot-term programs that would be particularly specialized and thus, better understandable by participants with no studies on agriculture. The conduction of seminars on circular entrepreneurship was also suggested to engage farmers cooperatives that could allocate some fields for experiential education, where the circular management of the by-products/wastes could be implemented.

Stakeholders in education in Croatia believe that Universities of biotechnical sciences, Polytechnics, Public and Private public universities are an example of the best practice in terms of education. They emphasize the advantage of community colleges as an institution that can additionally devote itself to participants who have previous knowledge and provide them with practical experience of working in olive growing. As good practices in Portugal, training material developed under the TANGO-Circular project and a teaching resource developed by the Bee Circular association were identified.

Generally, short courses on circular economy should occur in such ways that will lead to the development of skills in the field of application. Specifically, participants of such courses should gain knowledge on the technological developments in circular economy, take advantage of the skills and technological knowledge offered and have skills regarding the economic analysis of such opportunities and models on circular economy. Each participant after the end of the course should be able to focus on the method or product that fits best to his/her needs or interests and apply circular practices for the production of value-added products. It was also suggested that participants should be evaluated after the end of the courses in order to earn a certificate.

11.4. Potential Institution that Could Offer Courses on Circular Business Practices in the Olive Sector

During the interviews conducted with stakeholders in education, as potential institutions that could provide a training course on circular business in olive growing, generally respondants from all countries recognized **universities and vocational training institutions as key potential proveders** for such programs in the future.

The respondents from Croatia highlighted the University of Zadar and University of Applied Sciences of Rijeka, where they are employed, various institutions for training adults and the Croatian Employment Service which offers vouchers for the acquisition of micro-qualifications and partial qualifications from various sectors, partially co-financed by the Croatian Employment Service and EU Funds. Other similar faculties and universities that were discovered can be found in Table 11 (D2.1 Croatia, 2024).

Portugal also has quite a few potential institutions that could offer the mentioned training such as Bragança Polytechnic Institute, Castelo Branco Polytechnic Institute, Lisbon Superior Institute of Agronomy, Portalegre Polytechnic Institute, Évora University, Beja Polytechnic Institute and various vocational schools (medium-length courses) and training centers (short courses).

Several respondents and interviewees from Spain emphasized that vocational training centres and agricultural schools are already equipped to provide specialized training in various aspects of olive oil production and could effectively integrate circular economy principles into their curricula. Furthermore, it would be highly beneficial if these institutions collaborated closely with technological centres or research institutes. Such partnerships could enhance the programs by incorporating cutting-edge research and technology, thereby providing a more comprehensive and up-to-date education in circular business practices. Additionally, some participants have proposed that circular economy training should be developed into a full undergraduate degree. Such dedicated degree program could provide more comprehensive education on circular economy practices and would offer ample time and resources to delve deeply into these practices, preparing graduates to implement and innovate within the sector effectively.

The incorporation of circular economy principles into academic programs could also benefit from collaboration with industry experts and research centres. These partnerships would ensure that the training remains aligned with current industry needs and advancements, thus enhancing the relevance and impact of the educational offerings.

Greece recognized ELGO-DIMITRA as the organization that could possibly in the future organize a program on circular entrepreneurship. Co-operatives, in collaboration either with Universities, ELGO-DIMITRA or with other organizations could organize short courses in the field of circular entrepreneurship in the olive sector. Also waste management units, composting companies, or companies that produce organic fertilizers could also have interest in conducting such courses/conferences in circular entrepreneurship education in the olive sector.

As much as it is important to determine potential institutions that could offer courses in the field of circular economy in olive sector, it is also important to identify **potential recipients of those courses**. Recipients could be **professionals in the olive sector** with a university degree, i.e. a bachelor's or master's degree preferably in agricultural and agri-food sciences, or at least professional training in the area; **farmers or agricultural labourers**, with less training, who may only have the minimum mandatory schooling, but have professional experience; **undifferentiated professionals** with no previous training or who are **unemployed but want to work in the area of valorizing by-products** from the olive oil industry; **young students/trainees** who are finishing their mandatory schooling or are looking to study at university in order to work in the olive oil sector afterwards.

12
Conclusion

12. Conclusion

12.1. Summary of Key Insights

Olive oil production is an important agricultural activity in many countries. As this industry grows, so does the generation of by-products and waste, which presents challenges but also opportunities for sustainable practices. The main by-products of olive oil production are olive pomace, wastewater from the olive mill, pits and olive leaves and branches. However, with the adoption of circular practices, these by-products can be transformed into valuable resources.

Olive pomace, made up of water, pulp residues, and pit fragments, is the most abundant by-product. Traditionally viewed as waste, many companies now recognize its potential as biomass for energy production or as raw material for the extraction of olive pomace oil. Likewise, olive pits can be utilized as a renewable fuel due to their high calorific value and low ash content, rendering them a valuable resource for energy production. Research conducted for the purpose of CIRCOLIVE project showed that olive by-products and/or waste are mostly sold in Portugal, Italy and Spain, while the respondents from Greece and Croatia mainly do not sell their olive by-products/waste.

On the other hand, wastewater poses a significant challenge because it is highly polluting due to its high content of phenolic compounds. Recent studies indicate that, if treated properly, it can be used for irrigation or for extracting bioactive substances with antioxidant and antimicrobial properties. This presents new opportunities for valorization, enhancing the sustainability of the olive sector. Nevertheless, the sector is still in the early stages of transitioning to a circular economy model, with many companies facing challenges related to costs, technologies, and the complexity of regulations.

Despite the fact that waste valorization technologies and the circular economy practices are constantly updated through the advances in the academic research, they are often not combined with business innovation, or they are not implemented on an industrial scale. Although by-product streams have potential economic value they are not always exploited through their utilization by sustainable ways, e.g. as fertilizers or soil improvement products after their pretreatment and composting. In terms of the circular economy, producers and mill owners find both advantages and disadvantages within the sector. Producers are driven by the need to reduce costs and increase income, recognizing that the effective management of by-products can lead to significant financial benefits. There is also an awareness of sustainability, with many motivated by the desire to minimize environmental impact and promote more sustainable agricultural practices. The availability of technology and knowledge plays a crucial role, as access to modern solutions makes it easier for producers to implement efficient by-product management practices. Legal obligations and support mechanisms, while not the strongest motivators, still influence decision-making, particularly when there are clear regulations and incentives in place. In addition, the growing interest in research and development of new technologies offers a pathway to improved efficiency and added value in by-product management. For instance, producers are exploring the potential to enhance the value of by-products through the production of compost or derivative products like cosmetic creams. There is also a recognized opportunity to tap into emerging markets that prioritize environmental sustainability. On the other hand, the economic viability of these innovations is still uncertain due to high costs and regulatory constraints.

In most of the countries studied, olive farming is predominantly characterized by small-scale, fragmented operations, with a large number of small farms. This high concentration of smallholders, coupled with the relatively small average farm size, underscores the dominance of family-run farms in the olive sector. While this reflects a rich tradition of olive cultivation that spans generations, it also presents challenges for scalability, modernization, and the adoption of new technologies. Balancing tradition with innovation will be key to ensuring the sector's sustainability and growth in the future.

At the moment, the existence of educational programs or educations that deal exclusively with the topic of the circular economy in olive growing has not been established in any of the countries. However, there are certain types of education in which the topic of the circular economy is covered in a smaller part. Almost all respondents in this research are interested in attending an education that would deal exclusively with this topic. The incorporation of circular economy principles into academic programs could also benefit from collaboration with industry experts and research centres. These partnerships would ensure that the training remains aligned with current industry needs and advancements, thus enhancing the relevance and impact of the educational offerings. From this research, it can be concluded that with proper education and adequate financial support, relevant stakeholders in the olive oil industry could start or improve their application of sustainable practices in the olive sector. The review of existing institutions dealing with education identified potential institutions that could provide vocational education and training on the topic of the circular economy in olive growing. The survey results revealed that the majority of respondents would prefer online way of attending the courses developed in the field of circular economy in the olive sector. Combining face-to-face classes with online learning provides students with greater flexibility and accessibility. This blended approach is complemented by the integration of agronomic, economic, and technological skills into training programs, which is considered a best practice for preparing participants to tackle the challenges of the circular economy.

12.2. Recommendations for the implementation of circular practices in olive sector

The implementation of circular practices in the olive oil sector is crucial to ensuring long-term sustainability and competitiveness. However, this transition requires significant investments in innovative technologies, regulatory simplifications, and a cultural shift among producers.

In the olive oil production process, sustainability efforts should also be focused on energy efficiency, waste management and reduction of greenhouse gas emissions. Many olive mills invest in energy-efficient technologies, such as modern centrifuges, which reduce energy consumption during oil extraction. It is also recommended to use renewable energy sources, such as solar panels, to power olive mills, which further reduces the sector's carbon footprint. Management of waste and by-products from olive processing is a significant challenge in olive oil production, but also provides opportunities for sustainable practices.

Pruning residues can be efficiently managed on-site by shredding them with a mulcher, which enriches the soil with organic matter. This practice also promotes a circular economy by reducing the need for external organic inputs in olive groves. Additionally, these pruning residues can be composted and repurposed as organic fertilizer, or pelletized to create a valuable renewable energy source. Both options offer sustainable solutions for managing agricultural waste while supporting environmental and economic goals in olive farming.

Olive pomace and vegetable water, the primary by-products of olive processing, should be repurposed rather than treated as waste. Olive pomace, left after fruit processing, can be composted and applied as an organic fertilizer to enrich olive groves. Additionally, it can be mixed with household green waste and bio-waste for composting, reducing overall organic waste. However, a significant challenge lies in the lack of organized composting systems, as well as the considerable time and space required for this process. Despite these hurdles, composting remains an effective method, improving soil structure and fertility. Moreover, alternative treatment options such as the production of adsorbents, antioxidants, biopolymers, enzymes, and natural dyes, areas currently receiving increasing research interest, offer promising potential for industrial applications. Further development of these innovative solutions is essential to enhance their economic viability and wider adoption in the olive sector.

To transition towards a circular economy in the olive sector, priority must first be given to minimizing waste generation and optimizing water and energy use to reduce the overall environmental footprint. A key step in this direction is the implementation of two-stage centrifugation systems, which are among the most effective technologies for controlling and reducing water consumption during the production process, while also managing wastewater. Encouraging the reuse of purified water from olive mills for irrigating olive groves is a crucial sustainable practice. In areas with high production, establishing wastewater treatment plants and implementing technologies that enable controlled application of treated wastewater to the soil can help minimize contamination risks while conserving water resources.

Additionally, reducing water consumption can be achieved through practices such as the use of ecological sewage systems, improved waste management in olive oil mills, and oil-water separators to recover residual olive oil and reduce pollution. These strategies not only contribute to resource efficiency but also play a vital role in protecting the environment and promoting sustainable olive production.

An increasing number of olive mills are adopting equipment to extract pits from olive pomace, a valuable energy-rich by-product. These pits can be used as a fuel source in their raw form or as organic fertilizer, offering sustainable reuse options. To further optimize resource management and waste reduction, it is recommended to integrate digital technologies, such as sensors for monitoring soil quality and composting efficiency. Digitalization enables data-driven decision-making, improving production efficiency and enhancing sustainability throughout the olive supply chain.

Economic incentives, such as subsidies and tax breaks, are crucial to encouraging the adoption of circular practices. Companies investing in sustainable technologies or developing circular business models should be rewarded to reduce investment costs and drive the transition toward a more sustainable and competitive economy. Only through a comprehensive strategy involving all stakeholders in the supply chain can the olive sector, particularly in Italy, effectively address future challenges.

The gap in vocational education and training underscores the urgent need for specialized, integrated programs that equip professionals with the skills required to implement circular economy practices. A lack of technical knowledge is a major barrier to widespread adoption of these practices. Developing a standardized, comprehensive curriculum across educational institutions is recommended, covering key areas such as waste valorization, resource efficiency, sustainable production processes, and the integration of circular business models. This would provide stakeholders with the necessary expertise to implement circular approaches in olive farming.

Collaboration between universities, research centers, and industry stakeholders is essential for disseminating knowledge and fostering the development of new circular economy solutions. Increasing practical training opportunities—through internships, workshops, and hands-on projects in companies already practicing circular methods—is also critical. These experiences will provide students with real-world insights into how circular economy principles can be applied, ensuring the next generation of professionals is well-equipped to drive sustainable innovation in the olive industry.

12.3. Policy Implications and Recommendations

The management of olive by-products and waste is advancing, driven by environmental regulations and a growing awareness of sustainable practices. The organic residues from olive production can be effectively valorized within the circular economy framework, which is a central focus of the European Union's common agricultural policy and its green transition strategy. To promote the adoption of circular practices in this sector, coordinated efforts are required from institutions, businesses, and training providers. Key to this effort is the creation of policies that incentivize technological innovation, especially for small and medium-sized enterprises (SMEs) in the olive industry.

One of the primary recommendations for advancing this market is to establish uniform legislation and standardized terminology for olive by-products and waste. Currently, regulations governing agricultural waste, including olive pomace and vegetation water, are complex and fragmented, particularly at the regional level. Harmonizing these regulations through national policies is critical to facilitating the adoption of circular practices. Clear standards and precise guidelines for sustainable by-product management would reduce regulatory uncertainty, which is a significant barrier to investment in green technologies. Additionally, streamlining environmental licensing processes and creating a more flexible legal framework for waste reuse would enable the implementation of innovative circular economy technologies more effectively.

Financial challenges also hinder small producers from investing in sustainable technologies. To address this, a system of tax incentives and subsidies should be established, specifically targeting small and medium-sized producers. This could include tax exemptions for by-product recovery technologies and waste treatment systems, as well as subsidies for innovative projects aimed at the utilization and valorization of olive by-products and waste. These financial incentives would motivate stakeholders to embrace circular economy practices, particularly within the olive-growing sector. Providing targeted support, including financial assistance, technical expertise, and access to advanced technologies, is crucial for enabling smaller producers to adopt sustainable practices.

Establishing standardized guidelines for by-product management across the olive industry is equally important. Such guidelines would ensure consistent, effective practices and help bridge the gap between larger and smaller producers. To promote widespread adoption of circular practices, institutions must collaborate with vocational education and training (VET) providers to develop comprehensive professional education programs. These programs should integrate skills related to circular economy principles, technological innovation, and sustainable resource management. Policies that incentivize continuous education in the olive sector, including support for courses on these topics, are essential for addressing skills gaps and disseminating best practices across the industry.

Lastly, strengthening collaboration between research institutions, the private sector, and public policymakers is vital to driving innovation and accelerating the transition toward a sustainable economy. Political institutions must facilitate partnerships between universities, research centers, and olive companies to foster knowledge exchange and stimulate the development of new circular economy solutions. By establishing knowledge-sharing platforms and offering economic incentives, public policies can play a pivotal role in transforming the olive sector toward greater sustainability and circularity. Only through a joint commitment from all stakeholders can a sustainable future for the olive industry be achieved.

13

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14
Appendices

14. Appendices

14.1. Glossary of Terms

Olive Grove: A plantation where olive trees are grown, primarily for producing olives used in oil extraction.

Olive Mill: A facility where olives are crushed and processed to extract virgin olive oil.

Pomace: The solid residue left after the extraction of olive oil, consisting of olive skins, pulp, seeds, and stems.

Technological water: potable water used in processes. In production of virgin olive oil is used for washing of fruits, but also for washing of machinery and the facilities, and in three-phase extraction is added to the olive paste for facilitating centrifugal extraction, becoming part of virgin olive oil extraction residues.

Two-Phase Centrifugation: A method of olive oil extraction with minimal addition of technological water that separates the oil from the residues, resulting in two phases: oil and wet pomace.

Three-Phase Centrifugation: A method of olive oil extraction with addition of significant amount of technological water that separates the oil, from the residues, resulting in three phases: oil, dry pomace and the residual liquid phase, also called wastewater from the olive mill, constituted mostly from technological and vegetable water.

Wet Pomace: The solid by-product from the two-phase extraction process, having a high moisture content.

Dry Pomace: The solid by-product from the three-phase extraction process, containing less moisture than wet pomace.

Olive Pit: The hard stone inside an olive that contains the seed. It is often separated after the oil extraction process and can be used for various purposes like energy production.

Biomethane: A type of biofuel that can be produced from organic materials, including olive pomace, through anaerobic digestion.

Organic Fertilizer: A natural fertilizer made from organic matter, such as composted olive pomace, that is used to enrich soil fertility.

Composting: The process of decomposing organic matter, such as olive pomace, to create nutrient-rich compost for soil amendment.

Purification and Reuse (Irrigation): The process of treating residual water from olive mills to make it safe for use in irrigation.

Purification and Release: The treatment of residual water from olive mills before releasing it into the environment to prevent pollution.

Circular Economy: An economic system aimed at eliminating waste and the continual use of resources, often implemented in olive oil production by reusing by-products and minimizing environmental impact.

Mulching: A technique where organic materials, like olive pruning residues, are spread over the soil surface to improve moisture retention, soil fertility, and reduce weed growth.

Pellet Production: The process of compressing organic materials, such as olive pits or pomace, into small, dense pellets used as fuel.

ECO Labeled Organic: Products certified and therefore labelled as organic, produced under specific environmental and organic farming standards, ensuring they are produced without synthetic pesticides or fertilizers.

Integrated Production: A farming system that combines the best of conventional and organic practices to reduce chemical inputs and enhance environmental sustainability.

Oil refinery: A facility that processes low-grade olive or olive pomace oils, producing edible refined oils from olives or olive pomace.

Landfill Disposal: The practice of disposing of olive by-products in designated landfills, typically for waste that cannot be reused or recycled.

14.2. Survey Questionnaires and Interviews

14.2.1. ANNEX 1: Online survey targeting MSMEs in the olive sector

ANNEX 1: ONLINE SURVEY TARGETING MSMEs IN THE OLIVE SECTOR

QUESTIONNAIRE ABOUT METHODS AND POSSIBILITIES OF USING OLIVE BY-PRODUCTS AND WASTE IN OLIVE SECTOR

This survey is launched as the first consultation activity of the project ***"Developing skills for introducing circular business models and digital technologies in olive oil sector (CIRCOLIVE)"***, a three-year project co-funded by the European Union under the Erasmus+ Programme.

The project aims to support the EU transition to the Circular Economy by improving/enhancing the circular business skills in the olive oil sector in Spain, Italy, Greece, Portugal and Croatia, in order to promote the adoption of circular entrepreneurial models for waste and by-product valorization of the whole olive value chain.

The answers to this survey will help us in developing of skills for introducing circular business models and digital technologies in olive oil sector.
In this survey definition of ***Circular Economy*** presents methods and possibilities of using olive by - products and waste in olive sector.

The survey takes **about 10 - 20 minutes**. Responses will be treated **anonymously** and the results will be used for **CIRCOLIVE project purposes only**.

Your answer is valuable to us and we thank you in advance for your time and effort.

- questions for olive producers

1. Volume and characteristics of olive production on the enterprise
   - Total area under olive groves ________ ha
   - Total number of olive trees by age
     - Olive groves until 5 years _______________ trees
     - Olive groves between 5 to 20 years _____________ trees
     - Olive groves older than 20 years ______________trees

2. Technology used in your olive grove (one answer)
   a) Conventional
   b) Ecological with eco-label
   c) Other

3. Which technological interventions related to circular economy you apply in olive grove:

	Yes-No
Inert plant cover from chopped pruning	
Incorporation of the remains of pruning into the soil	
Inert plant cover from cut grass	
Grass cutting	
Livestock nutrition	
Use organic fertilizer	
Precise incorporation of mineral fertilizer	
Integrated agriculture /reduction of chemical pesticide	
Precise pesticide application	
Storage, recovery and use of stormwater	
Use of wastewater/purified water for irrigation	
Drip irrigation and controlled of water consumption	
Precise irrigation	
Use of photovoltaic panels	
Use of hybrid motors	
Use of biofuels	
Use of recycled and recyclable containers and packaging	
None of the above	

4. Type of soil management in your olive grove
    a) Soil cultivation
    b) Mulching (mulching permanent grassland and pruning residues)
    c) Combination of the first two ways
    d) Other:

5. Intensity of winter pruning in your olive grove
    a) Every year
    b) Every couple of years
    c) None

6. Intensity of summer pruning in your olive grove

   a) Every year

   b) Every couple of years

   c) None

7. Select the procedure with olive pruning residues in your olive grove (multiple answers are possible)

	Procedure
a)	Mulching (mulching permanent grassland and pruning residues)
b)	Controlled burning with or without returning the ashes to the olive grove
c)	Composting
d)	Firewood
e)	Production of firewood pellets
f)	Livestock nutrition
g)	For pharmaceutical and food industry
h)	Production of useful and decorative items (furniture, jewelry, dishes, etc.)
	None of the above
i)	Other (specify):

8. Choose your motives and barriers for utilizations of pruning residues

		Types of procedure						
		a)	b)	c)	d)	e)	f)	g)
Motives for implementation	Lower costs and/or higher incomes							
	Legal obligation and/or support							
	Available							

	technology, knowledge and experience
	Awareness of sustainability
Barriers for implementation	High initial investment and costs
	Legal restrictions or insufficient support
	Lack of technologies and knowledge
	Lack of social and environmental awareness

9. Rate your agreement with the following statements about the advantages and disadvantages of mulching pruning residues in an olive grove:

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree
The most cost-effective way of using pruning residues	1	2	3	4	5
A positive effect on the structure and content of organic material in the soil	1	2	3	4	5
Useful because it prevents the growth of weeds and erosion and conserves moisture in the soil	1	2	3	4	5
Disease development and pest attack are encouraged	1	2	3	4	5
Increases the danger of fire outbreaks	1	2	3	4	5

Negative impact on soil pH value	1	2	3	4	5

10. Rate your agreement with the following statements about the advantages and disadvantages of burning pruning residues:

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree
The plant residues burning is in accordance with the principles of good agricultural practice	1	2	3	4	5
Useful because pests and disease are controlled	1	2	3	4	5
Extracting the branch from the plantation requires a lot of work	1	2	3	4	5
It is not useful because valuable organic material is lost	1	2	3	4	5
It is harmful to the air and the local ecosystem	1	2	3	4	5

11. Rate your agreement with the following statements about the advantages and disadvantages of composting pruning residues:

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree
Organic waste in landfills is reduced	1	2	3	4	5
The obtained compost is a quality organic fertilizer	1	2	3	4	5
Composting is a demanding procedure that needs knowledge that I do not have	1	2	3	4	5
There is no organized composting system in the area	1	2	3	4	5

The composting process is very long and requires a lot of space	1	2	3	4	5
Composting creates unpleasant odors and attracts insects	1	2	3	4	5
Improper composting can result in the spread of disease in the plantations	1	2	3	4	5

12. Rate your agreement with the following statements about the advantages and disadvantages of producing firewood pellets from pruning residues:

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree
Pellets have a high energy value	1	2	3	4	5
Pellets are an ecological energy source	1	2	3	4	5
Equipment for pellets production is expensive	1	2	3	4	5
The production of pellets requires a large consumption of energy, so their production is not ecologically justified	1	2	3	4	5
There is no organized system for the production of pellets in the area	1	2	3	4	5
The price of pellets is high compared to other energy sources	1	2	3	4	5

- questions for olive mill owners

13. Installed olive mill capacity: ___________ kg/hour

14. Amount of processed olive fruits in the last 3 years:

2021 year - _______________ olive fruit tons

2022 year - ______________ olive fruit tons

2023 year - ______________ olive fruit tons

15. Which technology is used in the olive oil extraction process in your olive mill:

a) Two-phase centrifuge system (oil + wet pomace)
b) Three-phase centrifuge system (oil + olive mill wastewater) + dry olive pomace) Other: _________

16. Is the extraction of pits carried out in your olive mill?

Yes - No

17. In witch phase are pits being separated?

a) Before milling the fruits
b) After oil extraction, from dry or wet pomace
c) Not applicable

Other: _______

18. How is olive wet or dry pomace used or disposed of in your enterprise?

a) It is scattered on agricultural soil immediately after processing
b) Heap composting
c) As biofuel
d) For production of ecological products.
e) For the production of construction materials.
f) Livestock nutrition
g) Is disposed of at a waste disposal site

Other (specify): _____________________________

19. If is implemented in your enterprise, how long does the composting process last

___________ months

20. Rate your agreement with the following statements about the advantages and disadvantages of composting olive pomace:

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree
Composting is the best available way to use olive pomace	1	2	3	4	5
The obtained compost is a high-value organic fertilizer	1	2	3	4	5
Compost improves the structure and biological activity of the soil	1	2	3	4	5
Olive pomace decomposes slowly, so composting takes at least 12 months	1	2	3	4	5
Due to the low content of organic acids and phytotoxins soil amendment with olive pomace compost is not an issue of environmental risk	1	2	3	4	5
The legal regulation of olive compost application in agriculture is complex	1	2	3	4	5

21. Rate your agreement with the following statements about the advantages and disadvantages of using olive pomace as biofuel:

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree
Pomace is a high-quality renewable energy source	1	2	3	4	5

Pomace has a low energy value	1	2	3	4	5
The process of using pomace as biofuel is expensive and unprofitable	1	2	3	4	5

22. How is used olive mill wastewater in your olive mill?
    a) Recycling and reuse in the olive processing
    b) For production of biofuel (biomethane)
    c) Purification and reusing (irrigation)
    d) Purification and release into the environment
    e) Other (specify): ______________________________

23) Rate your agreement with the following statements about the advantages and disadvantages of using olive mill wastewater for recycling and the potential use

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree
Olive processing costs are reduced	1	2	3	4	5
Reducing fresh water consumption contributes to ecological sustainability and reduces the negative impact of olive processing on the environment	1	2	3	4	5
Recycling olive mill wastewater is expensive and unprofitable	1	2	3	4	5
The disposal/use of recycled olive mill wastewater is subject to strict legal requirements	1	2	3	4	5
It is useful to purify vegetable wastewater for irrigation	1	2	3	4	5
It is useful to extract valuable compounds, such as polyphenols, from vegetable wastewater	1	2	3	4	5

24) For which purpose are olive pits used in your olive mill?

   a) Energy source in its original form
   b) For the production of pellets or briquettes
   c) For the production of biomaterials. Organic fertilizer
   d) Other (specify): ______________________________

25) Rate your agreement with the following statements about the advantages and disadvantages of using olive pits as an energy source:

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree
The amount of waste from olive processing is significantly reduced	1	2	3	4	5
A natural, renewable energy source is obtained, for which is an increasing demand	1	2	3	4	5
Pits have a lower energy value compared to wood	1	2	3	4	5
High investments are required in a pits processing	1	2	3	4	5

26) Do you sell olive by-products and/or waste obtained in the olive sector?

No – Yes,

Please list all the products you sell and mention as first the most important one according to your opinion.

27) (If the previous answer is YES) Rate your agreement with the following statements related to the placement and sale of the previously mentioned first product:

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree

I have no problem with the placement of this product	1	2	3	4	5
I am satisfied with the selling price	1	2	3	4	5
I plan to increase production	1	2	3	4	5
Most of the customers are within a radius of 50 km	1	2	3	4	5
The domestic market does not yet recognize this product	1	2	3	4	5
I need to improve the production technology of product for the market	1	2	3	4	5
It is necessary to educate customers about the benefits of the product	1	2	3	4	5
I have to invest a lot in marketing and publicity	1	2	3	4	5

28) Rate your agreement with the statements about the opportunities and threats of the circular economy in the olive sector

	I don't agree at all	I don't agree	Neither agree nor disagree	I agree	I fully agree
Public subsidies stimulate olive growers to apply circular economy measures	1	2	3	4	5
The processing of olive by-products and waste requires large capital and labor investments	1	2	3	4	5
Olive by-products and waste from the olive sector pose a threat to the	1	2	3	4	5

environment if they are not processed according to the principles of the circular economy					
There is no organized olive by-products and waste processing system in the area	1	2	3	4	5
The legislative framework limits the development of circular economy in olive sector	1	2	3	4	5
It is necessary to raise awareness about the benefits of implementing circular economy in olive sector	1	2	3	4	5

Questions for both groups: Socio-economic characteristics of respondents

29) Respondent's gender
   a) Male
   b) Female
   c) I don't want to answer

30) Respondent's age _____________ year

31) Enterprise location

   Country _________________

   Region __________________

32) Respondent's education
   a) High school and lower
   b) Bachelor degree
   c) Master degree
   d) PhD

33) Education in the field of agriculture

Yes - No

34) Do you completed a course, training or education of circular economy in olive sector and/or agriculture?

Yes - No

35) If YES, enter the following information about education:

a. Education name ____
b. Organization in charge (Vocational Education and Training (VET) provider). ____
c. Duration

   ____
d. Method of implementation

   Online

   In presence

   Hybrid mode
e. Obtained title

   ____

36) Enterprise size:
1. Micro (<10 employees)
2. Small (<50 employees)
3. Medium sized (<250 employees)
4. Large size (>250 employees)

37) Agriculture is for my household
a) The only source of income
b) Predominant source of income (> 50%)
a) Additional source of income (< 50%)

38) I am interested in attending a training course focused on how to valorize olive by-products and waste

Yes - No

39) Select the preferred method for attending a training course focused on how to valorize olive by-products and waste

a) Online

b) In presence

c) Hybrid mode

40) Dear respondent,

Thank you for your time and contribution to Circolive project

41) I consent to have the information stated above used by the CIRCOLIVE project partners solely for meeting the purposes of this survey.

Yes – No

In case you want receive information about the project and activities, please enter your e-mail

14.2.2. ANNEX 2: Structured interview with circular business agro-food experts/professionals

ANNEX 2: Structured interview with circular business agro-food experts/professionals

Date:

Location:

Enterprise name:

Enterprise email address (in case you want receive further information about the Circolive project):

Enterprise size:

1. Micro (<10 employees)
2. Small (<50 employees)
3. Medium sized (<250 employees)
4. Large size (>250 employees)

Type of enterprise (possible multiple choice):

1. Olive producer
2. Olive mill owner
3. Olive by-products/waste recycle facility owner
4. Other: _____________

Interviewees' business role:

1. Executive
2. Manager
3. Operations and production

Interviewees' years:

Interviewees' educational level:

1. Main information about your enterprise.
- length of business, number of employees,
- description of olive production (total number of olive trees, production area etc…)
- total amount of processed olive fruits per year
- oil mill capacity per hour
- all types of olive by-products/waste being processed
- all types of products obtained
- years of experience of by-products and waste processing
- total amount of each type of olive by-products/waste processed per year
- Other information

2. Describe the olive processing technology
- Describe the olive by-products and waste processing technology also if you know future technology trends if you know
- Describe the normative of each olive by-products and waste obtained from 100 kg of olive fruits (percentage of olive oil, wet/dry pomace, olive mill wastewater, pits)
- In case you use just one type of olive by-products and waste please explain the reason why you didn't use other olive by-products and waste

3. How are the obtained product/products from olive-by products and waste being used?
- Reusing by the enterprise or in the field, selling on the market, other
- If you sell on the market, describe the marketing mix 4P (price, product, place, promotion for each new product/products)
- Identify the major producers and industry players in the olive waste sector
- Try to predict market development of olive waste products (risk/challenges and opportunity/potential)

4. Which is your motives/drivers/preferences for processing olive by-products/waste?
- Social motives (more sustainable awareness/practice, social benefits/cohesion, culture/tradition, collaborative economy)
- Economical (cost savings – shared use, cheaper resource, resource of greater efficiency, higher income – additional income from products, increased sales, increased price from differentiation)
- Political-legal-institutional (legal obligations, systems of certification, institutional support)
- Innovation and technology (technology, knowledge, training)

5. Did you have any barriers or gaps when starting the olive by-products/waste business?
- Social (lack of environmental – social awareness, culture -tradition, deficiencies in collaborative economy networks)
- Economic (high initial investment, higher costs, lower profitability)
- Political-legal-institutional (regulatory limitations, lack of institutional supports and insecurity regarding incentives and aid)
- Innovation and technology (obsolescence, little development – access to technologies, lack of technical knowledge)

6. Describe the current situation in the context of barriers or gaps?
- Comment off all barriers from the previous question.

7. Do you plan remaining in olive by-products/waste business in the future?

- Expand business - increase the amount of olive by-products/waste processing capacity, add new types of olive by-products/waste processing or reduce/give up…)

8. Which is the Strengths, Weaknesses Opportunities, and Threats and for further developing the olive by-products/waste business?

Strengths (Strengths describe what an organization excels at and what separates it from the competition)
Weaknesses (Weaknesses stop an organization from performing at its optimum level)
Opportunities (Opportunities refer to favorable external factors that could give an organization a competitive advantage)
Threats (Threats refer to factors that have the potential to harm an organization)

- Can you identify any other best practices in your country regarding circular economy in the olive sector?

9. Do you have any education in the field of circular economy?

If yes, who is the provider of this education, duration of education, way of conducting the education (In presence, online, hybrid mode)
If no, do you plan participating in an educational program on the circular economy in the olive sector?

10. Are you interested in participating in the educational program on the circular economy in the olive sector which will be final results of the CIRCOLIVE project?

Which way of conducting the education (In presence, online, hybrid mode) you prefer?

14.2.3. ANNEX 3: Structured interview with VET providers

ANNEX 3: Structured interview with VET providers

Date:

Location:

VET name:

VET email address (in case you want receive further information about the CIRCOLIVE project):________

Type of VET:

1. University
2. Polytechnic
3. Institute
4. Public Open University
5. Private provider
6. Other (specify):___________________

Interviewees' role:

1. Executive
2. Manager
3. Lecturer
4. Other____________

Interviewees' years:

Interviewees' educational level:

1. Main information about VET provider
    - Length of business
    - Number and type of employees by role (teaching, training, administrative…)
    - Area of provided education (agronomy, forestry, economy, other)
    - Other information

2. Do you offer courses on circular business practices in the olive sector?

If - YES (question no. 3), If – NO (question no. 4)

3. Main information about available educational courses related to circular business practices in the olive sector:
    - Name and number of courses per year

- Duration of each course in hours
- Average number of participants who successfully passed the courses (per courses and per year)
- Method and techniques used for training
- Obtained title after course finishing
- What are the recognition paths/qualification validation methods used by the offered trainings?
- According to your knowledge, is the concept of circular business practices in the olive sector taught in other Institutions (regular (higher) education programs, in vocational training (VET) or in adult training in general)?

4. Which institutions offer courses on circular business practices in the olive sector (Universities, VET providers, adult training institutions, private institutes/schools, etc.)?
   - If there isn't any, which institutions could potentially offer courses on circular business practices in the olive sector in the future (universities, vocational education and training providers, adult training institutions, private institutes/schools, etc.)?

5. What training methods and techniques are mostly used and are suitable for circular business agro-food professionals' training? Theory + practices, Practices + educational visits, combination or something else, please describe.

6. What are the identified best practices in your country regarding the education programs in the context of circular business practices?
- offered trainings, training methods, recognition paths/qualification validation methods

7. In your opinion, which lecturer profiles (specialties) should have an institution offering courses on circular business practices? - agronomy (or a specialist in olive growing), ecology, food technology, economist, others

8. Do participants of the circular economy course in the olive sector need any prior specific degree or knowledge/skills?

9. If yes, which ones?

10. What skills the participants will have after passing the circular economy course in olive sector, and where they can apply their knowledge?

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