Identifying Barriers and Facilitators Affecting the Valorization of Olive Oil By-products

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ABSTRACT

Title: Identifying Barriers and Facilitators Affecting the Valorization of Olive Oil By-products
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English: The climate crisis, inflicting extreme weather conditions and crop-killing high temperatures, caused agricultural producers to examine their methods to see how they can become more sustainable to combat negative effects. One way to increase sustainability, adopting a circular economic model of production, involves designing out or valorizing waste into economically valuable by-products that can be sold and used as a resource for other products. The production of olive oil, an economically important product for countries like Spain, Portugal, Italy, and Greece, creates waste like wastewater, solid olive waste, and solid-liquid bagasse that has a negative impact on the environment if left untreated. The objective of this thesis is to identify which barriers are preventing olive oil producers from adopting a circular production model, and which factors are facilitating producers into successfully applying this model. To investigate, we conducted interviews with a random sample of three olive oil producers located in Portugal. The results indicated that the barriers were high transportation costs from rural areas, having a low-risk approach to sustainability, and the lack of vital financial and technological resources. The facilitators that were helping producers become more sustainable included access to funding from the EU, having a high-involvement sustainability approach, and the commitment to make investments in innovation and technology. The implications of these findings emphasize the need for governmental organizations to create financial and technological resources for olive oil producers to innovate their production systems with sustainability integrated into the new design.

Portuguese: A crise climática, infligindo condições climatéricas extremas e temperaturas elevadas, levou os produtores agrícolas a examinar os seus métodos para verificar como poderiam combater os consequentes efeitos negativos e tornarem-se mais sustentáveis. Uma forma de aumentar a sustentabilidade, adotando um modelo económico circular de produção, envolve valorizar resíduos em subprodutos economicamente valiosos que podem ser vendidos e utilizados como recurso para outros produtos. A produção de azeite, um produto economicamente importante para países como Espanha, Portugal, Itália, e Grécia, cria resíduos como águas residuais, resíduos sólidos de azeitonas e o bagaço de azeitona sólido-líquido, que tem um impacto negativo no ambiente caso não tratado. O objetivo desta tese é identificar quais as barreiras que impedem os produtores de azeite de adotar um modelo de produção circular, e quais os fatores que facilitam aos produtores a aplicação bem sucedida deste modelo. Para investigar, realizámos entrevistas a uma amostra de três produtores de azeite situados em Portugal. Os resultados indicaram que as maiores barreiras eram os custos de transporte nas zonas rurais, ter uma abordagem de baixo risco para a sustentabilidade, e a falta de recursos financeiros e tecnológicos. Os facilitadores que ajudariam os produtores a tornarem-se mais sustentáveis incluíam o acesso ao financiamento, ter uma estratégico abordagem de sustentabilidade e o compromisso de efetuar investimentos em inovação e tecnologia. As implicações destas descobertas sublinham a necessidade das organizações de criar recursos financeiros e tecnológicos para que os produtores de azeite inovem os seus sistemas de produção com sustentabilidade integrada na conceção.

Keywords: by-product, biomass, phytochemical, valorization

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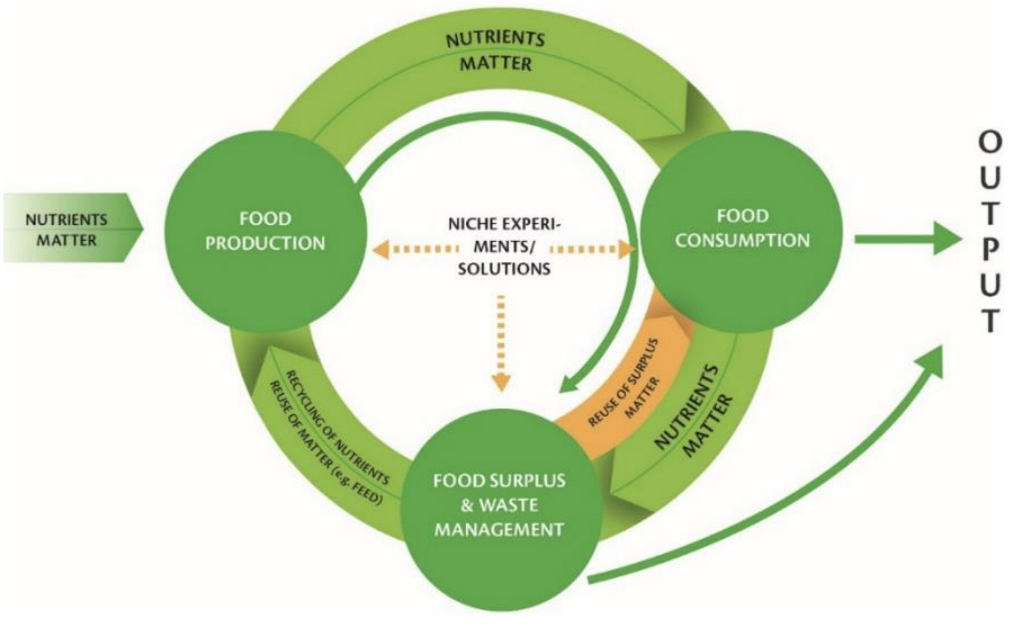
1 INTRODUCTION

Olive oil, widely popularized for being a primary source of fat in consumer diets, has a variety of health benefits. Benefits range from decreasing cholesterol affecting the cardiovascular system, and lowering inflammation and oxidative stress (de la Lastra et al., 2001). An emphasis on olive oil combined with high amounts of vegetables, fruits, fish, and whole grains — known as the Mediterranean Diet — is linked to a lower risk of heart disease, lower risk of diabetes and stroke, and overall a lower mortality rate (Willet, 2006; Gullón et al., 2020; Jeguirim et al., 2020). The increased awareness of the benefits of the Mediterranean diet has led to an estimated production increase to accommodate demand (International Olive Oil Council, 2021). Over the last decade, this was reflected in an annual increase of 0.1% in world-wide consumption. Every year around 1.6 million tons of olive oil are produced in the Mediterranean region, which represents 96% of the global olive oil production (Jeguirim et al., 2020).

The challenge posed by such surge in production is both at the economic and environmental level posed by the amount of waste and by-products that arise from the production of olive oil. According to the EU's Waste Framework Directive, by-products are substances resulting from a production process, the primary aim not being producing that substance. Waste can be turned into a product or secondary raw material only if it has (1) undergone a recovery operation, and (2) complies with criteria such as being used for a common purpose, an existing market or demand for the substance, and it does not lead to adverse environmental effects (European Commission, 2008). Due to the processing of olive oil, solid, liquid, and solid-liquid substances that are also produced. These substances can be classified as both by-products and waste. Of particular attention is a liquid known as olive mill wastewaters, high in toxicity levels, and a solid-low liquid form of pomace, olive tree biomass residues, and olive stones (Negro, 2017). Such toxicity is harmful to the environment, causing serious problems such as soil and water degradation and atmospheric pollution (Batuecas et al., 2019; Dermeche et al., 2013; Mikdame et al., 2020). Once released into the environment, "olive pomace has harmful effects on the environment due to its toxicity and antimicrobial properties" (Alcazar-Ruiz et al., 2021). The harmful effects are due to the high content of phenolic compounds, organic matter, phosphorus, among others, accelerating the contamination of aquatic organisms (Brito, 2016). The high levels of toxicity are due to its low acidic pH (around 5.6), and can also include chemicals like nitrogen, ammonia, and phosphorus (Batuecasa and Tommasi, 2019).

The issue at hand results from farmers not building production systems to eliminate olive oil waste through their production cycle. Instead, it is typically disposed of into the surrounding soil, nearby bodies of water, landfill, or it is incinerated. Governments and policy makers are urging for solutions, because the repercussions are costly. For example, the UN's Food and Agriculture Organization (FAO) reported that inefficiencies along the current linear, i.e., without reintegrating by-products and/or waste, food production cycle cost up to $2 trillion per year, if social and environmental impact are considered (Jurgilevich et al., 2016). If the disposed waste was factored out and instead formed into a circular model, it could become a virtuous loop: The main input being nutrients and matter (like olive tree seeds, sun, and water) to be transformed into olive oil for consumption as the main output. Then any surplus and olive waste are returned back into the loop and managed by having nutrients recovered to enhance growing more olive trees or other crops, being reused and transformed into by-products like fertilizer which also help crops, or being transformed into a product like biofuel which can be sold to other industries as a separate output.



Source: Transition towards Circular Economy in the Food System, Jurgilevich et al., 2016

From an economic perspective, there are also financial benefits for using the circular economic model to factor out waste and focus on product valorization. Preventing waste not only contributes to a lower cost for virgin raw materials as inputs, but waste streams provide a source of renewable raw materials that then can go on to create other valuable products (Vardanega et al., 2015). This presents a beneficial cost-savings for the producer as they save money on inputs while also creating an additional income stream of selling more value-added products. Circular economic models also economically benefit society as a whole by contributing to the creation of the new 'green market' through providing jobs and promoting converting waste into by-products like animal feed, biofuel, and other bioproducts (Duque-Acevedo et al., 2020)

This circular economic model can also be applied to olive oil production, because olive waste contains valuable elements that can be extracted and turned into by-products used as raw ingredients across various industries — these include phenolic compounds, carbohydrates, organic fatty acids, and mineral nutrients (Dermeche, 2013). The phenolic compounds (0.5 - 24 g / L) are hydroxytyrosol, tyrosol, caffeic acid, p-coumaric acid, vanillic acid, singic acid, gallic acid, luteolin, quercetin, cyanidin, verbascoside, as well as carbohydrates, fibers and pigments (Cedola et al., 2020). Food production already uses some of these compounds for animal meat, or as a preservative for their fenolic and antifungal properties (Gullon et al., 2020; Mikadame et al., 2020). The cosmetic and pharmaceutical industries also benefit from sustainable sources of antioxidants, which are also found in olive oil waste (Rodrigues et al., 2015). Such reintegration of this waste in other valuable products is aligned with the framework of a circular economy. In moving away from the current linear production model of today's global economy, a circular economic model has the five pillars of designing out waste, building resilience through diversity, using energy from renewable sources, thinking in terms of systems, and thinking in cascades (Esposito et al., 2018). Common valorization methods of agricultural waste include composting, anaerobic digestion, and a biorefinery that can extract valuable chemical compounds and either create another chemical, biofuel, or raw ingredients for the cosmetic or pharmaceutical industries (Vandermeersch et al., 2014, 58).

Research has noted the potential for by-product valorization with strong social and economic impact by building on territorial resources that can help to cope with food scarcity, hold cultural significance, contribute to landscape preservation and become a source of inspiration (Britton, 1991). The outcome results in more resilient communities and better economic performance. Our study aims to understand current practices of olive oil producers in regard to by-product valorization. Specifically this thesis aims to understand the following questions:

1) How are olive oil producers addressing waste and valorization of by-products?
2) What options do farmers use for waste treatment (environmental problem) and by-product valorization (economic perspective)?
3) Understanding the valorization potential. What are the challenges and facilitators towards implementation of a more circular economy in olive oil production?

This thesis aims to provide answers to these research questions, as the need to decrease the negative environmental impact of olive oil production becomes increasingly important as the climate crisis, popularity of olive oil, and the Mediterranean Diet continues on.

The remainder of this thesis is structured in the following manner: Part two reviews the relevant literature on sustainability, the circular economy framework, and olive oil production to provide a solid foundation to which this thesis builds upon. Part three outlines the selected methodology chosen to collect data. Part four demonstrates how the results of the collected data relate back to the theoretical framework outlined in Part two. Part five uses the presented findings to draw conclusions, discusses the academic and managerial implications of the findings, and the limitations and potential opportunities for further research.

2 LITERATURE REVIEW

This section highlights the current state of sustainability measures in present-day society, introduces the concept of a circular economic framework, and demonstrates how the agriculture sector is addressing sustainability. Lastly, it delves deeper into the olive oil production process, the problems that arise with the waste that results from this process, and potential solutions for these problems.

2.1 Sustainability

With Earth's average temperature rising 1 degree Celsius since the Industrial Revolution, and a majority of the last 19 years being the hottest on record, 97% of climate scientists agree that humans have caused the increase in atmospheric greenhouse gases (GHGs) (Henderson et al., 2020). The main sectors causing the increase in GHGs are deforestation, the burning of fossil fuels for transportation, heating, and energy, and agriculture. If these industries do not incorporate sustainable changes into their operations to halt rising temperatures, it is projected that carbon dioxide concentrations will reach 450ppm as early as 2030 (Henderson et al., 2020).

The areas of the world that are most likely to experience the heightened negative impact of climate change are the vulnerable lower-income countries that depend heavily on agriculture, and are thus more susceptible to hunger as climate change affects food production (FAO, 2017). The primary ways climate change negatively affects food production is the increased frequency of extreme weather conditions and higher temperatures, both of which contribute to a decrease in crop yields (FAO, 2016). Due to the current agricultural sector constituting around 20% of total GHG emissions, mitigating the impact of climate change would involve "shifting to agricultural practices…that release fewer GHG emissions per unit of food" (FAO, 2013).

The challenge of developing effective sustainable agricultural practices, and implementing them concurrently on a global scale, is now so huge that the world has to unite. The concept of countries across the globe coming together to create sustainable development goals (SDGs) is not new. Its history can be traced back to the decades after the post-World War II peace era and into the Cold War era of the 1970s. It began with the 1972 Stockholm Conference on the Human Environment, then the 1980 World Conservation Strategy of the International Union for the Conservation of Nature, moving to the United Nations Conference on Environment and Development in 1992, with finally the 2002 World Summit on Sustainable Development in Johannesburg, South Africa bringing the prominent issue of sustainability into the 21st century (Robert et al., 2005). This background provides context to one of the most recent pieces of legislation that was passed by the European Union to aggressively combat climate change: the European Green Deal. The Green Deal, passed in 2019, sets ambitious climate action targets to be met in 2030 and 2050, aligns climate actions in key policies, and promotes ambitious climate action in cooperation with countries outside of the EU that are part of the Paris Agreement (European Commission, 2019). All of these key policies focus on cutting greenhouse gas emissions (GHGs), investing in technological research to innovate all sectors in society, and to preserve Europe's environment and biodiversity. For the preservation of Europe's natural environment and biodiversity, the European Commission created CAP — a common agricultural policy across the EU. CAP is set out to integrate sustainable and efficient agricultural and forestry practices so that the protection of the environment and food production can seamlessly coexist in the future (European Commission, 2020). This policy upholds environmental rules, helps protect farmland ecosystems by economically helping farmers meet challenges and come up with sustainable solutions, encourages organic farming that rely less on pesticides and fertilizers, and ensures natural resources like water, trees, air, and soil are managed sustainably in agriculture.

Another pillar of the Green Deal is the Farm to Fork Strategy — this strategy aims to innovate the current food system in the EU to ensure healthy food is produced sustainably and in a way that protects the environment, preserves biodiversity, and is economically fair to those in the supply chain. Since the growing, processing, packaging, and transportation of food is a large driving force behind the carbon emissions and air, water, and soil pollution that is causing climate change, this policy is urgently needed (European Commission, 2020). Policymakers are consciously aware that in order to accomplish the aims of the Farm to Fork strategy, a variety of factors are required for its success: addressing food insecurity and affordability concerns, adjusting European dietary consumption habits, and ensuring that all links in the food production supply chain are either carbon-neutral or have a positive environmental impact on the air, water, and soil. In terms of innovating the food supply chain, the farmers at the source are under pressure to rapidly transform their production habits, business relationships, and technological equipment using either natural or technologically advanced solutions to deliver the required climate results. This requires human and financial investment, with the promise that producers who implement farming practices that remove carbon from the atmosphere to help reach the Green Deal carbon goals faster should be economically rewarded.

How the sustainability goals of the Green Deal have impacted food production in the Mediterranean region, particularly for a crop as essential as olive oil production, have manifested itself in different ways. The most common methods olive oil producers have taken to reach these sustainability goals has been waste reduction by investing in efficient production systems, waste treatment to detoxify the acidic olive mill wastewater and pomace to decrease environmental pollution, and recovering the beneficial chemicals in olive mill wastewater and solid-liquid pomace to be reused as raw ingredients in other sectors (like cosmetic, pharmaceutical, construction, and wellness) (Souilem et. al, 2017).

2.2. The Circular Economy

In order for all participating countries to successfully reach the sustainability goals of the Green Deal, production systems for all sectors need to fundamentally rethink how they operate and change the status quo. A solution to eliminate unsustainable production methods is a transformative framework such as the one proposed by the circular economy approach (Kopnina, 2016). The Ellen Macarthur Foundation describes our post-Industrial era economy as having a linear 'take, make, and dispose' pattern that limits the progress society can make towards sustainability. The lifecycle of a traditional linear production model begins with the input of natural resources, the resources are transformed into a product, the product is consumed, and then the waste is disposed into the environment (Ellen Macarthur Foundation, 2013). The theoretical framework of a circular economy introduces the concept that production systems within an industry can be designed to be restorative, and "shifts towards the use of renewable energy, eliminates the use of toxic chemicals which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and within this, business models" (Ellen Macarthur Foundation, 2013). The principles of a circular economy can guide primary sector activities, because at its core it is the design of operations to create a full integrated cycle that feeds itself (Esposito et al., 2018). The circular economy will promote economic growth of society as well, since the minimized use of virgin resources can lead to an increase in producer profitability due to the decrease in costs of obtaining raw materials (Andersen, 2007). To begin adopting circular economy principles, the first fundamental trait that a producer can focus on is designing out the existence of waste — and if there is waste, it should be non-toxic and not negatively affecting the environment (Esposito et al., 2018). To design out waste, a producer can identify the sources of the natural resources used as raw materials for a product and look for diverse sources of where raw materials are supplied (Esposito et al., 2018). An example of this principle is if a paper producer has one wood pulp supplier that cuts down trees, instead this producer can work with multiple suppliers that provide them with recycled paper, wood scraps, and other by-products that normally would go to disposal. This diversity of sources will help the system be more resilient to handle unexpected shocks to the supply chain, because the whole production system is not relying on a singular supplier. To create an efficient system that can handle unexpected shocks, the producer has to utilize a systems-thinking mindset to be aware of all the interdependencies and co-movements involved (Esposito et al., 2018). Part of this systems-thinking mindset includes being aware of the system's dependency on a single energy source, and choosing a renewable source that does not pollute the environment in any way. If the production involves crops or nature, using one product to produce another is a circular economic trait called a cascading approach (Esposito et al., 2018). An example that integrates the two traits of a renewable energy source and a cascading approach is an olive oil producer. Olives and olive oil are both end-products to consume, and a source of biomass that could be transformed into biofuel, which can fuel farm machinery used to cultivate the olives in the beginning of the cycle. The challenge for agriculture is that practices are often based in traditional systems that are constantly adapted to new demands, thus not fully addressing the circularity principles.

2.3. Sustainability and Circularity in Agriculture

With the rise of industrialized farming practices in the 20th century, increased energy needs, in addition to the growing demand for natural resource-intensive meat-based diets, the operations of many agricultural producers did not address sustainability (FAO, 1996). As climate change continues to worsen, the increase in temperature will threaten the food supply of key commodities because extreme climate conditions and high temperatures inhibit crop yields (FAO, 2016). In order for the agricultural sector to adopt a circular framework, farmers using conventional agriculture methods first need to understand what constitutes a sustainable farming practice. Then, upon learning how sustainability can be integrated in agriculture, farmers can adopt the elements that fit the crops they produce and progress towards circularity. Agricultural sustainability can be defined as farming systems that are "making the best use of nature's goods and services whilst not damaging these assets" (Pretty, 2003). Making the best use of natural resources while not producing any negative externalities can be achieved through practices like nutrient cycling and soil regeneration, less use of non-renewable inputs that damage the environment or human health, and making better use of farmer's sustainability education to increase their capacity to independently solve problems like pests, irrigation, and forest management (Pretty, 2003). Using these practices to lead into designing a circular production model presents an opportunity to meet sustainability development goals in a more timely manner (Henderson et al., 2020).

Another reason why agricultural producers should work towards adopting a circular production model is based on the first element of a circular economy framework mentioned in section 2.2 of this thesis — designing out waste. Food waste presents a large problem in agriculture, as almost 30-40% of all food goes to waste because of a surplus of food not being purchased in retail stores, inefficiencies in processing, storing, preserving food after harvesting, and vegetal waste (Giovannucci et al., 2012). To combat an expected rise in agricultural waste as food production increases to accommodate a growing world population, the EU's Waste Framework Directive legislation clearly defines the different types of waste, ranks them according to a waste hierarchy (see figure below), and outlines goals for EU member countries to minimize the negative impacts wastes have on the health of people and the environment. The waste hierarchy is organized from the top being the biggest and most preferred option, to the bottom being the last resort that should be avoided. The largest section being 'Prevention' means that preventing waste from being produced is the preferred option — further emphasizing the 'design out waste' aspect of a circularity. If waste cannot be prevented it should be prepared to be reused, and if it cannot be reused it should be recycled. If it cannot be reused or recycled, it should be recovered to serve another purpose. It is only after waste has been evaluated to determine if it can be prevented, reused, recycled, or recovered that it should be disposed of in a landfill as a last resort.

Source: European Commission website ec.europa.eu

Under the Directive, olive oil production waste would fall under Chapter 2 in the List of Waste: *WASTES FROM AGRICULTURE, HORTICULTURE, AQUACULTURE, FORESTRY, HUNTING AND FISHING, FOOD PREPARATION AND PROCESSING*, "sludges from washing and cleaning" (European Commission, 2008). Under the waste hierarchy, waste is fully eliminated throughout the full food production cycle. Preventing any type of waste in the food system is key to the circular food production model being adapted in agriculture, because if waste is not being generated then there are no negative externalities on the environment during production. A visual representation of how the waste hierarchy, and by extension circular principles, can be applied to the food production system can be seen in the below image. The image shows how food for human consumption can be a part of the natural resource loop: Crops end up on the food plate and in co-products, crop residues are reused as the input for animal feed, grassland is used for animal feed, natural water is used in meat and co-product production, and the food waste (and co-product waste) is both used as animal feed and can be composted to help fertilize the arable land and grassland.

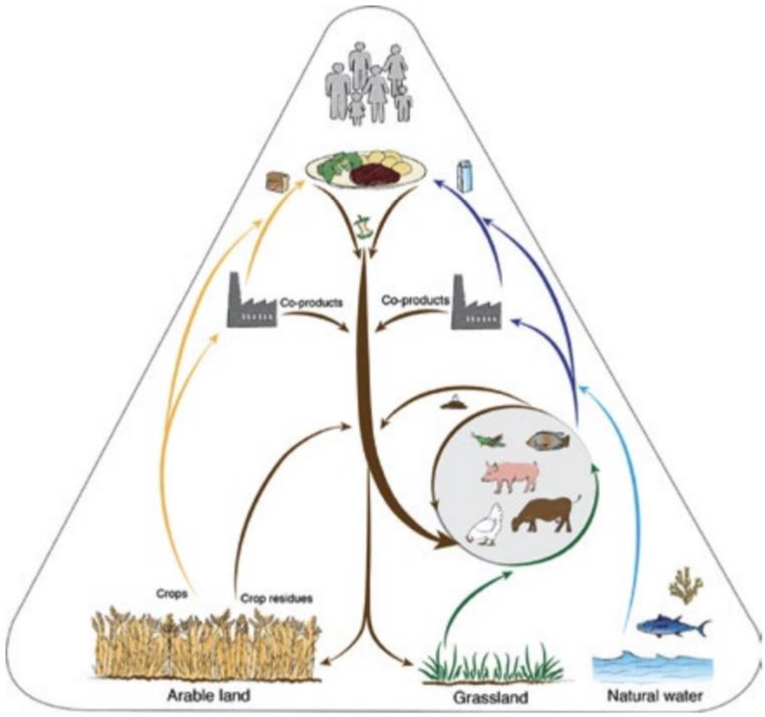


Figure 1
Visualisation of a circular food system (from: Van Zanten et al., 2019).

Source: *Circularity in Agricultural Production, 2018*

This image further illustrates when external waste (or waste that would normally be disposed of) is designed out of the production cycle there is no negative impact on the environment, and the cascading approach characteristic of a circular model in which one product (in the image labeled co-products) is used as a source for another product. In the agriculture sector, this circular model is important because it "will be beneficial to society and the economy as a whole…not only by minimizing the use of the environment as a sink for residuals but…by minimizing the use of virgin materials for economic activity" (Andersen, 2007). An alternate word for co-products being used as a resource for helping grow the arable land and grassland in the image is by-product valorization. Common methods used for transforming by-products into a valuable substance include composting into fertilizer, isolating compounds to be used as raw ingredients in pharmaceuticals or food supplements, fiber, biofuel, or putting biomass back into food production (de Boer et al., 2018). In the context of olive oil production, this thesis aims to identify the facilitators that enable and the barriers that prevent producers from adapting a more sustainable circular economic model through the use of olive oil waste as a resource for valorized by-products.

2.4 Olive Oil Production

The olive tree has been cultivated in humanity since the early civilizations, with the importance of olive oil marked by having its value reported as “five times that of wine and two and a half times that of seed oils”' in ancient Syrian documents ca. 2000 BCE (Uylaşer and Yildiz, 2014). With over 97% of the world’s olive oil production originating from the Mediterranean region, this crop continues to play a key economic and environmental role in the area (Gullon et al., 2020). What makes olive oil so important is the unique chemical composition: it contains fatty acids that help decrease cholesterol affecting the cardiovascular system, and has antioxidant properties due to its phenol compounds having the ability to neutralize free radicals that cause inflammation and oxidative stress (de la Lastra et al., 2001). As a result, substituting other forms of dietary fat (mayonnaise, butter, or margarine) with olive oil was associated with a 14% lower risk in cardiovascular disease and 18% lower risk in coronary heart disease among U.S. adults (Guasch-Ferré M et al., 2020). In another study that utilized economic models to estimate the theoretical cardiovascular healthcare costs savings in the U.S. associated with an increase in the adoption of the Mediterranean Diet, the model found that a 20% adherence level to the diet produced an annual savings of $8.2 billion (Jones J. et al. 2019.) For the people of the Mediterranean region, their lifestyle and way of eating — referred to as the ‘Mediterranean Diet’ — consists of cereals, grains, fruits, vegetables, legumes, nuts, dairy, fish, moderate wine and exercise, and olive oil as the main dietary fat for both cooking and as a salad dressing or dip for bread (de la Lastra et al., 2001, 934). With increased education on olive oil’s health benefits, its production is expected to grow to accommodate demand; this can be seen in the 5.8% increase of olive oil consumption in 2019-2020 (around 3.234.000 tons) as compared to 2018-2019 (International Olive Oil Council, 2021).

The by-products that come from olive oil production are classified as two main materials: a solid olive pomace and olive mill wastewaters, that when combined resemble a solid-liquid material made up of crushed olive stones, leaves, skin, pulp, and the water used to rinse the olives (also known as bagasse.) For example, in the region of Andalucía alone, with 4 million tons of waste being generated for every 5.8 million tons of olives processed, farmers and policy makers need action in order to address the severe environmental damage that untreated waste has and continues to cause to its surroundings (Ribeiro et al., 2021, p.1). The low pH of the olive mill wastewaters and pomace causes damage like soil contamination, water pollution, underground seepage, and odor (Paraskeva and Diamadopoulos, 2006). With no EU-wide regulations on olive mill waste management, practices like land disposal and discharge into nearby bodies of water contribute to increased toxicity in the natural environment (Rodrigues et al., 2015, 117).

2.5 Opportunities and best practices for by-product valorization in olive oil production

With olive pomace, wastewaters, and bagasse going to waste, producers are effectively discarding valuable compounds like minerals, polyunsaturated fatty acids, phenolic compounds, and fiber (Ribeiro et al. 2020, 2). An example of how these compounds can be extracted and used for valuable by-products is the food and wellness industry's search for a source of natural antioxidant dietary fiber. When obtained through a fractional approach, powdered olive pomace retains most of its compounds and is a source of insoluble dietary fiber, and beneficial lipids and proteins with an antioxidant capacity (Ribeiro et al., 2021). Adhering to a circular economic framework would decrease the amount of this discarded waste as it would involve valorization of the by-products. However, the factors currently preventing olive oil producers from making transformative changes include barriers like high waste transportation costs, the narrow view of sustainability, and the lack of financial, technological, and knowledge-based resources of all of the new valorization techniques that are being developed.

These by-products include biofuel, compost, cosmetics, and construction. The caveat is that because of the framework of a circular economy, the new bio-based products must have a high economic value as well as their needs incorporated into the design of the production system (Leitão et al., 2020). The most common application are:
Biofuel (fuel obtained through renewable resources like biomass) can play a key role as the world sees the urgent need to shift from using non-renewable and unsustainable energy sources like oil and coal that have been contributing to greenhouse gas emissions. The World Bank reports that 11% of corn production is used to create biofuel for the transportation sector (Giovannucci et al., 2012, p.10). A new technique called temperature pyrolysis, which exposes olive mill wastewater and solid olive pomace to thermal shock of 950C and atmospheric pressure, completely transforms these wastes into clean bio-coal with no by-products (Mechnou et al., 2020). A new carbonization technique like temperature pyrolysis

could be essential to making the valorization of olive oil waste profitable for the transportation industry as well as sustainable.

With more governmental policies being implemented in the past 10 years that require more investment into research and technological innovation, significant progress has been made in methods that previously produced animal feed and now help produce biofuels and bio fertilizer instead (Dietz et. al, 2018). Once the acidity of olive waste is treated and decreases to the point where it is unharmful, returning the material back to the olive grove as compost is a viable opportunity that the olive oil producers interviewed in this thesis are already utilizing in their groves.

The olive mill wastewaters and solid olive pomace can also be used to extract the raw ingredients in high-value products like cosmetics and skincare products. The chemicals that make these by-products a candidate for cosmetics and skincare usage are phenols like tyrosol, oleuropein, seed oil (like squalene) rich in fatty acids, and mineral nutrients. These chemicals contribute to anti-aging and have strong antioxidant properties which are highly beneficial for reducing oxidative stress on the skin (Rodrigues et al., 2015). In olive leaves (which are mixed into solid olive pomace), 11-40g of phenols/kg have been extracted (Conde et al., 2009) which indicates the abundance of beneficial chemicals that are present in by-products that could be put to cosmetic use.

Another sector that can utilize olive waste is the construction industry that can use the olive pomace as building materials. Researchers in Jaen, Spain experimented with adding 0-25% percentages of wet pomace to clay without added water to form bricks, and discovered that the bricks with 10% pomace had increased strength and high quality thermal conductivity. For the future of the construction industry, especially for construction companies around olive oil-producing regions, this could mean a lower carbon footprint and better insulated houses (Rubia-García et al., 2012).

There are still technological, financial, and innovation challenges that may be factors inhibiting today’s olive oil producers from valorizing olive oil waste into value-added by-products. This thesis aims to identify what are the inhibiting factors and potential resolutions, so that olive oil producers worldwide may use these findings to adopt a more sustainable production cycle.

3 METHODOLOGY

As discussed in the literature review, the main waste that is derived from olive oil production is a mixture of olive mill waste waters and solid olive pomace. When combined, it becomes a solid-liquid form of wastewater, olive pulp, olive skin, olive stones, and branches. What makes waste management challenging for producers is that olive pomace has a moisture percentage of over 65% and is toxic to soil if left untreated due to its texture and acidity (Ribeiro et al. 2020). Due to the difficulty of managing this waste, and the negative impact untreated olive pomace has on the natural environment, one might question if olive oil producers are seeking to or have already made progress towards the principles of a circular economy and designed out waste when they created their production system in order to eliminate both the management difficulty and negative environmental impact. However, through the data collected in this thesis, it was discovered that there are factors involved that are currently inhibiting olive oil producers from adopting the principles of a circular economy. To explore the reasons why these factors are affecting olive oil producers, a theory-building case study approach was applied. The following sections discuss this approach and present the sample.

3.1 Research Approach

Due to the lack of extensive research on how olive oil mills specifically in Portugal handle waste management and by-product valorization, in order to address the research questions a case study design was selected. A case study approach was selected for three main reasons: it allows for a process to test old or build new theory through comparing and contrasting conclusions from multiple cases, it allows the researcher to examine a case through multiple lenses on different levels of analysis that may be absent in a more quantitative study, and case studies allow qualitative data collection in the form of interviews, questionnaires, and observations (Eisenhardt 1989). Because this case study approach allows for the flexibility in its data analysis to choose a combination of a within-case analysis or cross-case pattern, it presents the ideal opportunity for this thesis to discover emerging themes in the in-depth interview data in addition to comparing the highlighted differences between each case. In the future, if researchers desired to build upon this thesis, investigators could include more cases either in Portugal or other olive oil-producing countries and collect similar interview data in order to validate the conclusions found in this thesis surrounding barriers and facilitators to by-product valorization.

The intent of this data analysis is to codify the data in a way that provides the same foundational structure for all three cases by applying the same overarching research dimensions in order to give each case equal opportunity to illuminate emerging themes in waste management and sustainability. Based on this structure, there are clear differences and similarities between the same research dimensions that affect how each company approaches the management of their olive oil production waste, and their views on creating a more sustainable circular economic production structure.

3.2 Case Selection and Data Source

In order to use case studies to build upon existing or create new theory, it is important to use one or more cases to collect descriptive empirical evidence that allow the researcher to create theoretical constructions or propositions (Eisenhardt and Graebner, 2007). Based on this requirement, the differences in company characteristics that distinguished between the olive oil producers played a significant role in creating the emerging themes in waste management and their overall sustainability approach. While smaller and younger companies might have one type of sustainability approach and mindset, the bigger and more traditional producers facing legislative requirements might have a different mindset that influences their waste management and sustainability practices.

Therefore, the case selection does include olive oil producers from different sizes and ages to allow contrasting cases highlight emerging themes in the real world (Yin, 2009). The selected producers were all located in Portugal, because of Portugal's history and economic emphasis on producing olive oil, the increased feasibility of conducting interviews in the same location and time zone, and its proximity to Católica Lisbon School of Business & Economics.

Below is a description of the interview subjects:

The oldest company of the subjects is classified in this thesis as Company 1. Located near the Upper Douro region of Portugal in Almendra, this is a family-run company with records proving its existence for over 370 years since the mid-17th century. Company 1 currently employs fifteen people involved in the olive oil production that stay throughout the year, but then 350 people are hired from all over the world during the harvest season. In terms of productive process, Company 1 uses the two-phase extraction method to produce 125.000 liters of olive yearly. In terms of markets, Company 1 exports to 42 countries spread throughout the world.

The second-oldest company, classified as Company 2, has been in existence for over 333 years, employs 12 people, uses the two-phase oil extraction method, and produces 40.000-60.000 liters of oil per year, 80% of which is exported to 14 countries.

The newest company, classified as Company 3, was established 14 years ago, has the two owners as the main employees throughout the year but hire 10 additional workers during harvest season, uses the two-phase extraction method, and produce 3.000 liters of olive oil per year which they retain 25% and export the remaining 75% to four countries.

Table 1 shortly presents the case studies, which participated in the study. The names of the respective companies are disguised and numerated to ensure confidentiality.

Characterization	**Company Description**
Size	1. Employs 15 people throughout the year, but then 350 people are hired during the harvest season 2. 12 people 3. 2 people throughout the year, 12 during harvest season
Age	1. Over 370 years 2. Over 333 3. 14 years
Location	1. Upper Douro region of Portugal, near Almendra 2. Trás-os-Montes e Alto Douro, near Mirandela 3. Idanha-A-Velha, Castelo Branco,

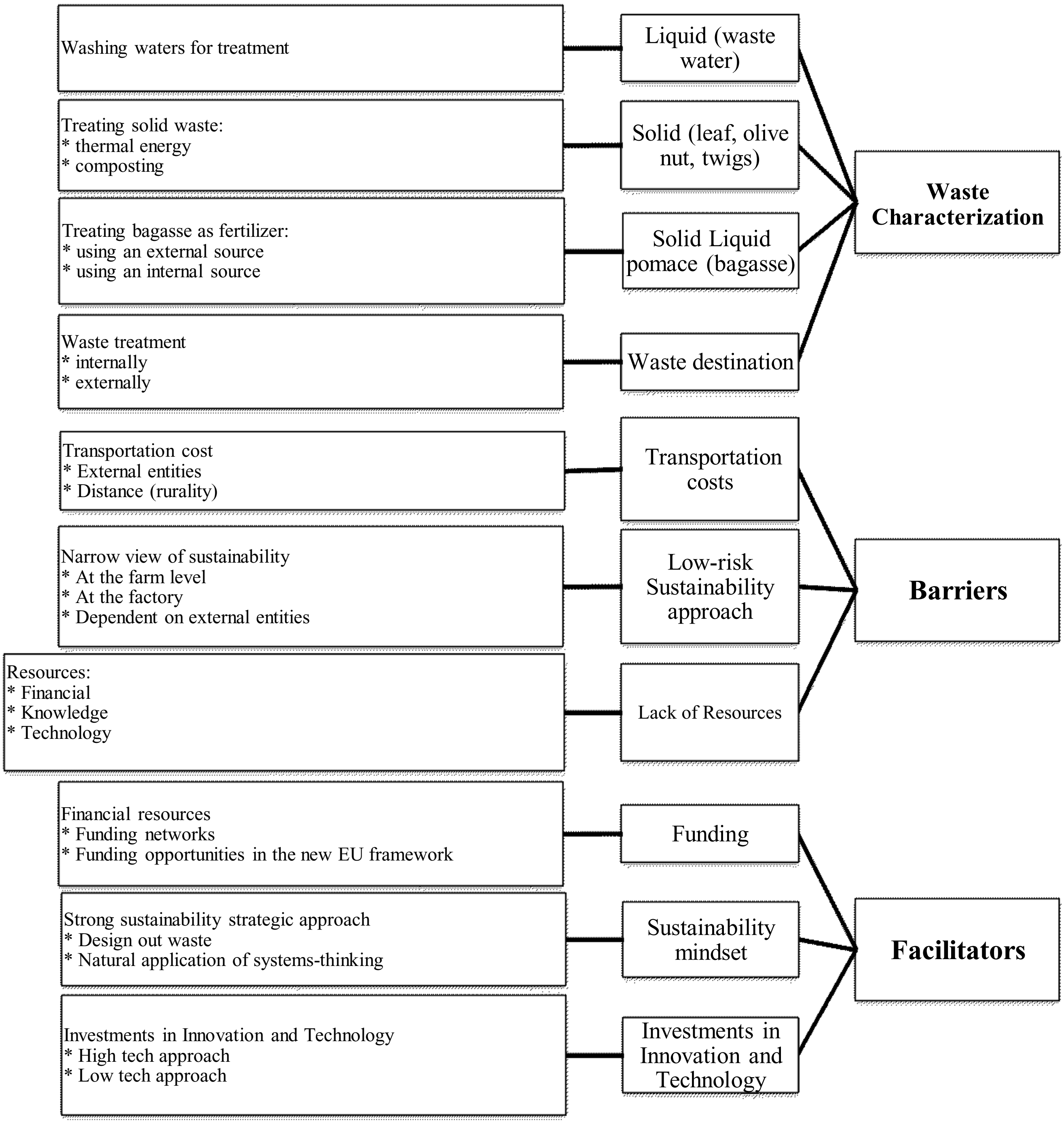
	Portugal
Type of olive oil production	1. Two-phase extraction method 2. Two-phase extraction method 3. Two-phase extraction method
Liters produced per year	1. 125.000 liters 2. 40.000-60.000 liters 3. 3.000 liters
Locations oil is exported	1. Export to 42 countries, the most important ones being Canada, sometimes the US, Japan, and Brazil 2. 20% locally, 80% exported to Brazil, United States, Japan, Poland, Denmark, Austria, France, Switzerland, Lithuania, Romania, United Kingdom, India, Ukraine, and Sweden 3. 25% to local restaurants, local stores and internationally 75% to England, France, Switzerland, Germany.

Table 1: Overview of interview subjects

3.3 Data Analysis and Structure

A case study approach using qualitative data requires a fundamentally different data analysis from quantitative data. This is due to the aim of this study focusing on understanding the multi-level linkages between the featured cases, in which the researcher does not have control over the operations within the cases located in the real world as opposed to being in an observable controlled environment (Patton and Appelbaum, 2003). After reading and organizing the interview content in word documents, the first fundamental step of the data analysis involved coding the data through the method of open coding (Strauss and Corbin, 1990). In an Excel spreadsheet, open coding was used to analytically break down the data by comparing the similarities and differences in the interviewer's responses, and then giving the responses a conceptual label to organize it. The benefit of this method was that through breaking down data into its most objective basic concept and moving them into categories, it enabled a more simplistic view of the data without biases so that they were allocated to their correct categories (Strauss and Corbin, 1990). After the coding process, the data was organized into first-order and second-order concepts under overarching research dimensions; first-order concepts are the 'facts' of a study, and second-order concepts are the 'theories' the researcher uses in analysis to explain the facts (van Maanen, 1979). In this context, the facts had been coded as the producer's direct responses to the interview questions, and then summarized into short descriptive sentences. Next, the theories were derived based on an analysis of what constructs can contribute to new theory that might answer the research questions, while still validating the facts (Corley and Gioia, 2004). Upon the conclusion of the data analysis, first-order concepts were consolidated into ten second-order concepts, falling under the categories of the research question involving waste characterization, barriers, and facilitators. The created second-order concepts explain the emerging patterns found in the first-order data to highlight the relationship between how the similarities and differences between olive oil producers influence the barriers and facilitators they face when approaching the circular economy opportunity (van Maanen, 1979).The final data structure is illustrated in Table 2:

Table 2: Data Analysis — First and Second Order Concepts


Washing waters for treatment
Liquid (waste water)
Treating solid waste:
* thermal energy
* composting
Solid (leaf, olive nut, twigs)
Treating bagasse as fertilizer:
* using an external source
* using an internal source
Solid Liquid pomace (bagasse)
Waste treatment
* internally
* externally
Waste destination
Waste Characterization
Transportation cost
* External entities
* Distance (rurality)
Transportation costs
Narrow view of sustainability
* At the farm level
* At the factory
* Dependent on external entities
Low-risk Sustainability approach
Resources:
* Financial
* Knowledge
* Technology
Lack of Resources
Barriers
Financial resources
* Funding networks
* Funding opportunities in the new EU framework
Funding
Strong sustainability strategic approach
* Design out waste
* Natural application of systems-thinking
Sustainability mindset
Investments in Innovation and Technology
* High tech approach
* Low tech approach
Investments in Innovation and Technology
Facilitators

4 RESEARCH FINDINGS

4.1 Results

The following section presents the empirical findings regarding the way olive oil producers manage agricultural waste, the different forms in which by-product valorization takes place, and the impact of the broader olive oil production activities. Corresponding direct quotes are translated from the original Portuguese statements.

The research dimensions are divided into the main factors of barriers and facilitators, with an addition of waste characterization to observe how the different producers manage the waste involved depending on the form. The above Table 1, which included information on production amount, company location, history, and team size, the connection between a company's history and its influence on their approach to waste management and sustainability can be made more evident. Based on the collected data, Company 1 is the oldest company, has the highest number of workers at any given time, and produces the most olive oil. Company 2 is in the middle with almost as long of a history, much less employees, and less than half the amount of olive oil produced. On the bottom end, Company 3 is the youngest company, with the smallest number of employees, produces the smallest amount of olive oil, and exports to the least number of countries. The different characteristics of each company heavily influenced the types of barriers and facilitators that affect each one's relationship to sustainability.

4.2 Waste Typology

For Waste Characterization, this is the subject where it is pertinent to not only distinguish the type of waste that each company produces, but also the amount, management method, and their perception of its value.
The most common method of olive oil production that is used by all three interviewed producers, the traditional two-phase method, produces three forms of waste that will be investigated in this thesis: a liquid (waste waters), solid (leafs, twigs, crushed olive skin and nuts), and a solid-liquid pomace that forms a sludge when the two combine (also known as

bagasse.) All three forms of waste are referenced in the findings below.

- **Solid: tree leaves, twigs, crushed olive skin and nut**

  For Company 1, the solid nut is dried out and reused as a heat energy source. Company 2 reuses the olive tree leaves to transform into on-site compost: “The leaves go to a trailer...this leaf is then reused, we have a composting center where we compost this leaf”

- **Liquid: olive mill wastewater**

  Company 2 produces 1300 tons of waste per year, which includes all of the liquid, solid, and solid-liquid forms. In the words of the manager at Company 2: “There are washing waters and the washing waters may contain some grease, these washing waters go into some tanks that we have for decantation and then that will be transformed into water or into a paste.”

- **Solid-liquid pomace: Also called bagasse - solid and liquid forms combined**

  The interviews revealed bagasse is the most common waste form, with transforming the bagasse to form compost to be used as fertilizer as the most common method of treatment. Company 3, producing 12 tons of waste per year including a combination of olive tree waste and the bagasse, states: “The pomace is composted together with the olive tree waste (from pruning and so on).”

  There is also a difference between producers who transform bagasse into compost in-house or those who delegate this responsibility to an external source. The owner of Company 1 manages this transformation in-house: “Just the bagasse that we leave in big vats to ferment over time to control the pH and then it goes back to the lands. This [treated fertilizer] is the main by-product.”

  The owner of Company 2, by contrast, manages bagasse externally: “the bagasse is not our responsibility, we deliver it [because] we simply have the hoppers there, a truck with a tank arrives at the right place and dumps and we do nothing with it.”

  Note: A hopper is farming machinery that delivers a commodity in bulk to another location.

In section 2 of this thesis, it was noted that common valorization methods of agricultural waste include composting, anaerobic digestion, and a biorefinery that can extract valuable chemical compounds to be used in other industries (Vandermeersch et al., 2014). Based on this knowledge, the collected data points to producers assigning a low prioritization value to valorization because the sample only utilized one valorization method out of the three most common — composting. While composting effectively treats waste from an environmental perspective by lowering the pH of the bagasse so it is no longer toxic, composting is valued very little from an economic perspective because fertilizer effectively has no resell value. The cause of this is likely due to there being no market creating a demand for fertilizer, as well as composting being a low-cost, low-technologically advanced solution that many farmers can replicate on their own. If farmers in this sample became more interested in prioritizing valorization and invested in another method like using a biorefinery, then the by-products that would be created (like chemical compounds that can be used as raw ingredients) would feed the demand for them from the cosmetic and pharmaceutical industries and thus be much more economically beneficial for the olive oil producers.

4.3 Barriers towards Valorization

Our data shows that the possibility for waste valorization are still in its infancy. The market structure in Portugal points to unique barriers that are inhibiting olive oil producers from optimizing their production systems in order to adjust to a circular economic production model of waste management.

4.3.1 Transportation Costs

The main barrier that stood in the way of all three producers was the high transportation costs associated with transporting their waste to other locations. Such locations that offer the opportunity for valorization are biowaste-based biorefineries that would be able to extract the beneficial chemical compounds found in olive oil waste, to which there are none located in Portugal (Nova Institute for Ecology and Innovation, 2017). Interviewees mentioned the possibility of biorefineries as customers for their biomass, and thus the absence of them in Portugal makes it difficult to provide waste as the raw materials for other industries. The challenge is that the biowaste-based biorefineries that are in Europe are concentrated mainly in Germany, Belgium, the Netherlands, Denmark, Sweden, and Finland — these are physically located far away from the main olive oil producer countries, and transportation costs do not cover the price paid per ton. Additionally, olive oil producers are generally in rural areas where access is more challenging. Company 3 specifically pointed to their isolated location that makes their transportation costs high, as stated in the interview: “[We feel]

Limitation in moving the products because [we] are in a more isolated region and the transport costs are high." Company 1 also emphasizes the cost of transportation as being a factor for keeping a majority of fertilizer for internal usage and selling the oversupply at a cost to the company: "After a few years people would give the fertilizer away but would never pay for the transportation to pick it up. Now, even for the transfer to pick it up we need to pay... this year we're going to sell some of the fertilizer because we have too much." There is also the absence of an efficient marketplace, for which they could potentially place their waste to be used as the raw materials for other companies. A market requires multiple buyers and sellers in order to thrive, and Company 1's oversupply of waste that they are selling at a cost to themselves indicates an inefficient market where there is not enough demand to offset the producer's transportation costs. Although there are organizations like CoLAB BIOREF (Laboratorio Colaborativo para as Biorrefinarias) that are aiming to help create a zero-carbon economy in Portugal by helping companies and institutions invest in biomass-based processes, there is currently no centralized location (either physical or digital) where buyers are demanding fertilizer or other agricultural waste, and therefore producers are not able to fill the void.

4.3.2. Lack of Resources (Financial, Technological Knowledge)

Our results also show that barriers include the high costs associated with new waste management technology. For reference, the owner of Company 1 stated "The machine I want to get to better manage the waste is super expensive." There is also a lack of knowledge on the outcomes of current technologies, which is critical in order for producers to know the machinery they should be investing in. The owner of Company 1 also mentions this notion of requiring more knowledge about a new piece of technology before investing in it: "There's studies out now about new homogenizers, so that's one thing I would like to change - but I'm waiting to see the trials." And Company 2 also shares this perception: "There are some studies that show that there may be a future valorization of the bagasse, but for now nothing is defined yet, I think there are some studies even at the level of the study center of Europe, Central and Northern Europe for animal feed, but for now this is still nothing." If there was a widely available centralized source that kept a continuously updated library of agricultural resources that included updated waste management techniques, valorization studies and outcomes, and information on the latest technological machinery, then producers would be able to make investment decisions at a faster rate.

4.3.3 Low-risk Sustainability Approach

As the negative impacts of the climate crisis worsen, serious action needs to be taken by agricultural producers to achieve the EU's sustainability goals within the next few years. Hence having a low-risk approach to sustainability presents a serious barrier between the valorization potential an olive oil producer could have, and their desire to progress in a more sustainable direction. For the interviewee at Company 1, sustainability of the operation lies at the core of the product of olive oil itself. By placing the most significance on the product, their strategic sustainability approach is low-risk and restricted since the design of the production processes and generated by-products are not perceived as part of the problem. Instead of discovering new ways to incorporate sustainability into their production cycle, Company 1 uses their organic olive oil production as a way to emphasize and promote that the firm is inherently sustainable. This is reflected in the respondent's own words when referring to sustainability: "We are the first ones doing organic olive oil since 1996. For us it's easier to make organics because our valley has less rainfall, so it's so hot that the sun usually kills the fly eggs on the olives so usually our olives don't have natural diseases." While one can infer that Company 1's olives do not require chemicals like pesticides, relying on the nature of the environment instead of actively pursuing an innovative sustainability plan reveals a low-risk, low-effort strategic approach.

Similarly, Company 2 also has a low-risk approach towards their waste. This can be evidenced by the excerpt "I think that the wet bagasse would be very difficult in the middle of the operation to be concerned about making this treatment or preparing for this treatment...the truck stops underneath twice a day and unloads and takes 17/18 tons at a time." Company 2 cites level of difficulty for bagasse treatment as the main reason to export it, instead of taking on the proactive responsibility to incorporate waste treatment into their internal production systems. Again, Company 2 cites additional low-risk, low-effort activities in the form of not heating their production facility to lower energy consumption and not having additives in their olive oil to promote their inherent sustainability: "in our case, we always work in cold weather, boiler off…a mill nowadays complying with all the rules has much less impact than any house in colder weather and makes a smaller amount of waste, also the olive oil is 100% olive juice so there is nothing added." The only responsibility Company 2 chooses is recycling, stated here: "in the normal recycling here that we have implemented and we have large containers, where we put the paper, plastic and glass. That is our responsibility to prepare." In both cases, producers chose the lowest risk approach to sustainability that require minimal effort to prepare. This presents a significant barrier to reaching a high valorization potential, which would require a higher level of effort and resources from the producers to achieve.

4.3.4 Influence of External Entities

The influence of external entities is also a barrier from a producer achieving higher levels of by-product valorization, because the partner's biases and personal motivations affect the producer's approach towards sustainability even if it is not in the producer's best interest. Here Company 2 describes their relationship with one of their academic external partners, Polytechnic Institute of Bragança, that involves them in studies that focus more on the sustainability of the end-product of olive oil rather than the sustainability of the production system itself: "every year we are always involved in many studies and of course many of them aim for a bigger production but 100% of them aim for the less impact we can have." By 'less impact we have' the interviewee refers to the product-focused aspects of sustainability that were influenced by the university's recommendations. These recommendations include using organic paint on the olive oil bottles, and incorporating more organic farming practices into the olive grove. While using organic paint and organic farming practices are indeed sustainable steps, adhering to recommendations from only one source presents a barrier to greater valorization potential that the producer could work towards if they focused more on innovating the overall production process to follow a more circular framework.

4.4 Facilitators

For Facilitators, these are the factors that are assisting each company in their current waste management process.

4.4.1 Funding

For Company 1, their main facilitators are the funding they received in the late 1990s, as stated "It was subsidized in the beginning to implant the new mill and to help expand us to the international market." This action initiated the transformation of the olive oil industry in Portugal, because the advanced technology of the new mill filtered out spoiled olives (which had previously been included in the production process) and helped create higher quality olive oil. The owner of Company 1 stated his interest in consistent investment in new technologies, as shown here: “People call me crazy but I love technology and I’m always updating something, every year I need something.” This high level of interest indicates that if producers received more funding to invest in advanced technology and machinery, it would likely be a facilitator of business success. Similarly, Company 3’s first facilitator was receiving funding from the European framework to assist in their organic production.

4.4.2 Sustainability Mindset

The biggest facilitator to applying a circular framework to the olive oil production process is the determined mindset of producers to commit to incorporating sustainability into all parts of the production process. Company 3 exhibits this mindset as they place the highest importance on ensuring every aspect of their production process and waste management is sustainable and related to regenerative agriculture. A circular approach to composting is employed by using native sheep to help break down olive tree waste, as mentioned here: “Sheep are fundamental in the approach to traditional olive groves because they end up controlling all the competing pasture to the olive grove in terms of water and mineral resources, at the same time that transforms it into assimilable manure, controls all the basal shoots (branches that remain on the trunk of the tree), are fundamental for soil regeneration.” Since olive tree branches, twigs, and leaves constitute solid waste, Company 3’s method of using sheep to help naturally eliminate this waste is a crucial element to a circular framework. In addition to having a strong proactive sustainability mindset, Company 3 also created a partnership with another company that shares their interest in sustainable innovation in agriculture: “in association with a company in Fundão that produces mushrooms will develop a technique called the Mycelium Net...The mushrooms will end up creating a communication network and symbiotic association (mycelium network) with the olive tree roots and is one of the soil recovery processes that the company is developing.” Unlike in section 4.3.4 with Company 2’s external entity heavily influencing their sustainability decisions, Company 3’s partnership is with an external entity who has a similar sustainability-driven mindset that will help Company 3 achieve their innovative goal.

Upon analysis of the interviews, all producers thoroughly answered how they currently manage their olive oil production waste, their view on sustainability and interest in increasing the valorization of by-products. The next section focuses on how the similarities and differences between their responses highlight conclusions on what may be preventing olive oil producers from adopting a more sustainable circular production framework, and the implications these conclusions can have on facilitating sustainable change in the future.

5 DISCUSSION

5.1 Conclusions

The objective of this thesis is to understand how olive oil producers are addressing the circular economy opportunity. In particular, to address the high level of waste that is derived from this process, even while being aware that untreated waste has a negative impact on the environment. Mark Esposito et al., 2018 outlined that the main principles of a circular economy are designing out waste, building resilience through diversity, working towards renewable energy, thinking in systems, and thinking in cascades. For olive oil producers, who are faced with the management of waste that is toxic to the environment if left untreated but has beneficial properties if valorized into economically valuable by-products, adapting these circular economy elements presents an advantageous opportunity for both the producer and nature.

First, our results highlight what is preventing producers from making steps to adopting a circular economy. The first barrier is high transportation costs. Transportation costs are relevant due to olive oil producers being located in relatively isolated rural areas of Portugal — usually a far distance from composting centers located closer to their urban customers, and a far distance from biorefineries which are concentrated in northern Europe. The further the distance the more costly it is for the producer to transport their waste, and the higher the cost the lower the incentive producers have to use an external entity like a biorefinery or composting center. Furthermore, the residues also have a high ratio of volume to weight which makes transportation a more challenging and costly issue. The second barrier is having a narrow view of sustainability. This narrow view of some producers enables them to take on a low-risk approach towards sustainability which makes it more difficult to achieve high-impact results. This narrow view of sustainability is applied to producers viewing the farm itself as sustainable due to natural elements like heat that require no additional work from the producer, limiting sustainable practices to lowering the energy consumption of the olive mill, and depending on external entities which may be biased. The third barrier is the lack of

financial, knowledge-based, and technology resources. Knowledge-based resources, such as continuously updated and widely available information on the latest valorization studies, sustainable farming practices, and waste transformation techniques, would be able to equip producers with the information they need to make faster investment decisions. Once this knowledge is accessed, financial resources like external funding are needed for them to be able to make bigger investments in new innovative technology on a consistent basis.
Secondly, our study points to facilitators that are enabling some producers in starting to address the circular economy opportunity. Most curious findings are the interest of producers in investing in innovative new technology; the available funding to do so, and the determined commitment to do so. We observed that a mind set to prioritizing sustainability enables the producer to overcome barriers like a lack of resources by identifying simple and affordable solutions that better allow the implementation of making progress towards circularity.

Our findings indicate that the concept of circularity in the olive oil sector is so new, traditional producers are still trying to understand and implement parts of it. Our findings illustrate that a producer's view on sustainability and the required mindset needs a more entrepreneurial approach. In fact, the youngest producer was the one able to implement most of the steps towards circularity. The entrepreneurial ecosystem that is emerging in olive production shows that entrepreneurs can succeed because it becomes possible to identify key players, understand where there are opportunities, and activate the resources needed for implementation (Cavallo et al., 2018). Therefore, to promote a successful entrepreneurial ecosystem within the olive oil production sector in Portugal, it is important to address and eliminate the barriers of a narrow view of sustainability and the lack of resources to give the owners of those companies the best chance for innovative success.
Additionally, company characterization data points to the infrastructure of the interviewed producers was originally designed in a linear production model with waste as an endpoint that the producers are forced to find alternative methods to manage. If these companies had designed their methods of production for circularity, then excess waste would not be the problem it is today. Another factor is the absence of incorporating systems thinking into their production. While producers like Company 2 have a low-risk product-focused sustainability approach, there is a lack of looking at the entire production as a whole cohesive interdependent system that uses renewable energy for the machines or valorizes the waste into valuable by-products to be sold. Lastly, transport costs plays a significant role. As these producers are family-run businesses that employ only 2-15 permanent employees, they have a

lower financial capability to invest in completely innovating their production to transform into a circular economic model in a rapid manner. Instead, these producers are interested in technology and innovation but take a slower approach and focus on innovating one machine or process at a time. A solution to this conundrum may involve the increase in circular economy awareness of both olive oil producers and the agroindustrial community at large, as well as widespread education of all of the valorized by-product options that exist.

5.2 Academic Implications

This dissertation adds an important contribution to the existing literature on the circular economy framework as it applies to the olive oil production industry, with a specific focus on Portugal. Through investigating how olive oil producers in Portugal in 2021 currently manage their waste, how the infrastructure of their systems are set in place, and how different companies navigate the challenge towards achieving circular economy opportunities, a deeper understanding of how elements of the entrepreneurial ecosystem concept play a role in the circular economy framework is revealed. As a management concept, an entrepreneurial ecosystem can be defined as "a network of interconnected organizations, connected to a shared focal firm or a platform, that incorporates both production and use side participants and creates and appropriates new value through innovation" (Autio & Thomas, 2014). In this collaborative ecosystem, participants cooperate using shared technology to create new products, satisfy customer needs, and innovate in ways that an individual company could not do alone (Moore, 1996). To apply this perspective to the circular economy framework described by Esposito et al. 2018, in order to innovate the olive oil production processes, producers have a higher chance of success if they collaborated together to learn from one another how to employ systems-thinking, how to design out waste, and how to think in cascades. The academic implication for researchers who supply policymakers with the knowledge to shape policies is to conceptualize a deeper understanding of an entrepreneurial ecosystem that requires producers to 1) use shared technology, and 2) have a shared focal firm or platform. Shared technology would be difficult to create due to both the high costs of new technology and the lack of readily available funding small farmers can access to use for technology investment. Additionally, having a shared focal firm or platform would be difficult due to the different strategic approaches the interviewed producers have towards sustainability — Company 3 placed a high importance on their sustainability-first mentality, while Companies 1 and 2 had a low-risk approach where they rely heavily on the environment and end-product packaging to promote sustainability. Thus, onboarding producers to the same mentality towards sustainability as well as providing them equal access to financial resources are needed in order to successfully put in place a circular economy framework.

5.3 Managerial Implications

As industries across countries in the European Union rapidly approach the deadlines of the predetermined sustainability goals in the near future, more attention, resources, and funding should be attributed to producers in the olive oil industry in order to provide them a simple and cost-effective opportunity to innovate their waste management infrastructure for circularity. The findings from this dissertation allow managers to be inspired to adjust their current strategies into new possible methods with an aim to increase effectiveness. Primarily, financial managers who are responsible for financing or subsidizing new innovative organic farming projects within the European Union can orient their current strategies towards focusing on addressing the factors preventing the adoption of a circular economy. Upon reading this thesis managers in this area would now see the importance of developing an ecosystem of support to circularity which would include support and guidance to those that want to apply for funds and do not know how to do it or where to find more information on changing their production systems. Olive oil producers are typically located in remote regions, and likely aren't seeking out external sources of funding on their own and thus need assistance. Furthermore, a lot of time and effort should be put into forming an extensive communication strategy to the olive oil producers in order to get as many farms to agree to partner with these programs as possible.

Supporting aspects of this ecosystem could potentially include the construction of venture-funded biorefineries built near the remote farms in of Portugal, Spain, Italy, and Greece, a European Union-funded policy grant program that is dedicated specifically to help small olive oil producers to innovate their systems' infrastructure, and setting up pre-determined transportation routes designed for the purpose of delivery tanks to pick up and deliver waste to another biorefinery location at no additional cost to the producer. The biorefineries would pick up and take in the waste from olive oil producers, extract the valuable chemical compounds, and provide these compounds to an extensive network of either innovative food production companies, beauty companies, or skincare companies that could utilize them as raw ingredients for their products. An example of this scenario already exists in PeelPioneers from the Netherlands, and has proven successful in creating a circular economy for the orange peels that are typically wasted in grocery stores in transforming them into other valuable by-products which end up back on the shelves of grocery stores. In the others, the high cost of innovation is no longer burdened on the small farmer to allow them to make the decision to choose circularity a smart financial one. Also, the Portuguese government can both make a monetary profit from the sale of the valorized by-products while at the same time increasing their level of satisfaction knowing they significantly will be helping decrease the olive oil industry's negative environmental impact and help meet their European Union sustainability goals in a timely manner.

5.4 Limitations and Future Research

This thesis acknowledges several limitations based on both the results of the interviews conducted and the available literature. Primarily, a relatively small sample size was interviewed due to the low response rate of olive oil producers that had been sent interview proposals over email. If the sample size included more producers, there would have been more information in the data analysis to strengthen the validity of the results and conclusions. Additionally, while the results were limited to producers only located in Portugal, it's possible if other olive oil producing regions such as Spain, Italy, and Greece were interviewed in a similar manner, the results of those interviews could have potentially contributed new insights that address how other producers have adapted their processes to a circular bioeconomy and how other countries can replicate their methods. Without the easily available spread of this information, it is unknown the length of time it will take for all olive oil producers in each country to adapt to more sustainable methods of production.

This thesis opens three possibilities to conduct future research. Along the route of technical innovation within industries that could utilize olive oil by-products, one missed area of opportunity that the interviewed producers did not consider as an economically viable avenue is extracting the polysaccharides and phenol compounds from waste to be used as raw ingredients in food products. Our interview subjects exported a majority of their olive oils in addition to selling their olive oil through commercial channels in Portugal, but many also received their olives from other farms around the country and then produced the oil for small wineries and quintas that sell exclusive olive oil blends along with wine. Thus, since these seller-producer relationships are already established, more research could go into developing a biorefinery that specializes in extracting compounds to be transformed into olive fruit pectin. Olive fruit pectin has quality gelling properties for jams as well as health benefits like containing oligosaccharides which can be a prebiotic source for gut health (Fernández-Bolaños et al., 2006), thereby creating a profitable market opportunity to sell jams and spreads alongside the oil made by the same fruit.

Another possibility for future research could focus on investigating innovative methods of organic matter decomposition and how organic fertilizer from olive oil production can be reused for other agricultural needs. The interview subjects all had the commonality of having their waste composted to be used as fertilizer, but high transportation costs was a barrier in their valorization potential for having this fertilizer be used in other far-off areas in addition to the producers lacking in the circular economy element of cascades-thinking of how this fertilizer can be used as one of the main sources for another product for another entity. Therefore, the investigation of new faster methods of organic matter decomposition, and how specifically olive oil-derived fertilizer can be best reused in another agricultural system physically close to olive oil groves, could be well worth the research. This could potentially be done through the development of a type of innovative chemical system that brings up the pH of an acidic vat of bagasse in a shorter span of time, rather than wait for it to naturally become less acidic over time as was the process for Company 1. If this technology was brought into fruition, the fertilizer inside the vat could be neutralized and ready to use in a matter of hours, which could have a strong positive impact on the growing cycle of the producer's own olive grove as well as providing a resource for nearby agricultural systems.

Lastly, the element of a renewable energy source is a part of the circular economy framework that all of the interviewed participants failed to address in their responses. To help promote the importance of this segment of the circular economy, it would be beneficial for the agriculture sector if more research could be conducted that focuses on new innovative technology that could be developed specifically to help olive oil producers transform their waste into a reliable and renewable power source. Company 1 had reported that their waste of ground nut of the olive was currently being used to heat homes located near the production facility, although additional research funding could be allocated towards identifying ways to use this process to supply the entire production facility itself with energy. The general knowledge and usage of how the olive nut and solid waste of the olive can be ground and pressed into blocks to then be used as a biofuel energy source has already been in use around the world for many years (Khdair & Abu-Rumman, 2020). However, the search for long-lasting renewable energy sources, that don't produce harmful greenhouse gases, remains an urgent priority during the climate crisis. The urgency to shift away from a reliance on carbon-emitting fossil fuel emphasizes the research need to quickly produce and harness biofuel from olive oil by-products, which could be significantly transformative to the world's energy sources. Thus, if more research attention and funding was put towards discovering how to transform olive pomace-derived thermal energy into clean energy to completely power the olive oil mills, that would be a major contribution into developing a circular economic model for the olive oil industry.

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APPENDIX

Table 3: Interview quotes collected on Company 1

		CARM [Company 1]
Production	**Liters of Olive Oil Produced**	We produce around 250,000 bottles of olive oil per year.
	Type of olive oil production	We use the two-phase extraction method - hot water makes it easier to extract the polyphenols and qualities of the olive oil.
	Locations oil is exported	We export to 42 countries to local agents that resell. The most important countries for our business are Canada, sometimes the US, Japan, and Brazil.
	Production mode	Centrifugation without the addition of water. 3 ways of milling depending on the sanity state of the olives, it depends on the site. We taste it in the moment. It's like a boutique meal, not a massive meal.
Company Characterization	**Size**	There are around 15 people involved in the olive oil production. I usually have 15 people that stay throughout the year but then during the time to harvest the crops I hire around 350 people that come from all over the world.
	Age	[Additional source carm.pt: CARM is a company that is still entirely owned by the family that launched its activity, with records dating back to the mid-17th century.]
Waste Characterization	**Liquid (waste water)**	
	Solid (leaf, olive nut, twigs)	They need to dry it out and then sell it. If it has the nut, they use for energy to heat homes.
	Solid-liquid paste (bagasse)	Just the bagasse that we leave in big vats to ferment over time to control the pH and then it goes back to the lands. This is the main by-product,
	Amount produced	
	Waste destination (if not all treated internally, where?)	No it's not transported, it's fertilizer only for us for the use of our vineyard and olive grove
Barriers	**High transportation costs**	After a few years people would give the fertilizer away but would never pay for the transportation to pick it up. Now, even for the transfer to pick it up we need to pay.
	High technology investment costs	The machine I want to get to better manage the waste is super expensive
	Market inefficiencies: high supply of by-product with little demand	this year we're going to sell some of the fertilizer because we have too much.
	Low-risk sustainability approach	We are the first ones doing organic olive oil since 1996. For us it's easier to make organics because our valley has less rainfall, so it's so hot that the sun usually kills the fly eggs on the olives so usually our olives don't have natural diseases
	Resistant Customer Mentality	One of the main barriers was people getting used to changing the process they've been used to forever
	Lack of knowledge	There's studies out now about new homogenizers, so that's one thing I would like to change - but I'm waiting to see the trials.
	Influence from external partners	Other farmers/producers - there's people always making new machines. And I go to the fairs to see what's new, what's going on, I talk with my friends in Italy
Facilitators	**Funding**	It was subsidized in the beginning to implant the new mill and to help expand us to the international market.
	Interest in Innovation	People call me crazy but I love technology and I'm always updating something every year I need something.

Table 4: Interview quotes collected on Company 2

		Casa de Santo Amaro [Company 2]
Production	**Liters of Olive Oil Produced**	the average production is between 40 to 60 thousand liters per year.
	Type of olive oil production	Right now the preferred option is integrated production. And then we have the 8 hectares certified as organic production and 38/39ha in reconversion...Two phases [is the method]
	Locations oil is exported	The main ones are Brazil, United States, Japan, Poland, Denmark, Austria, France, Switzerland, Lithuania, Romania, United Kingdom, India, Ukraine, and Sweden...I think that last year the export rate...is around 80% for export. At the domestic level it will be the rest.
Company Characterization	**Size**	The total number of employees in the company is 12
	Age	The company has been in the family since October 14th 333 years
Waste Characterization	**Liquid (waste water)**	there are washing waters and the washing waters may contain some grease, these washing waters go into some tanks that we have for decantation and then that will be transformed into water or into a paste
	Solid (leaf, olive nut, twigs)	the leaves go to a trailer...this leaf is then reused, we have a composting center where we compost this leaf...and we make this composting
	Solid-liquid paste (bagasse)	this paste we also put later in this watertight trailer and we also pour on top of the leaf to speed up the process in this composting center to speed up the decomposition process.
	Amount produced	If we make 1300 tons we have 80% or 80 something % of wet pomace, the rest, the difference is the oil...but maybe 75%/78%
	Waste destination	We compost the leaves, the bagasse is not our responsibility, we deliver it [because] we simply have the hoppers there, a truck with a tank arrives at the right place and dumps and we do nothing with it.
	Market value	a few years ago we still paid a valuation of 1€ per ton, now there is no kind of valuation
Barriers	**High transportation costs**	There are other cases where those who buy it for extraction pay something but then the mill also has to pay for transportation...the mill supporting this cost is a complicated thing
	Time constraint	We are a seasonal industry, we work 3 or 4 months a year with a lot of effort, we get the mill here and we work 24 hours a day for 2 and a half months and we never stop
	Low-risk sustainability approach	look as in the normal recycling here that we have implemented and we have large containers, where we put the paper, plastic and glass, That is our responsibility to prepare,
	Hands-off Mentality	I think that the wet bagasse we would be very difficult in the middle of the operation to be concerned about making this treatment or preparing for this treatment...that is why we also have a tank that is completely sealed and where there is no leakage and the truck stops underneath twice a day and unloads and takes 17/18 tons at a time
	Lack of knowledge	There are some studies that show that there may be a future valorization of the bagasse, but for now nothing is defined yet, I think there are some studies even at the level of the study center of Europe, Central and Northern Europe for animal feed, but for now this is still nothing
	Influence from external partners	every year we are always involved in many studies and of course many of them aim for a bigger production but 100% of them aim for the less impact we can have,
Facilitators	**Interest in innovation/internal investments**	It's like this, we annually make investments...here of course we always invest to guarantee the maximum quality, the working conditions,

Table 5: Interview quotes collected on Company 3

		Azeite Egitânia [Company 3]
Production	**Liters of Olive Oil Produced**	3 thousand liters of oil production per year.
	Type of olive oil production	Biological method for growing olive trees, and two-phase method of oil extraction.
	Locations oil is exported	They sell 25% to local restaurants, local stores and internationally 75% to England, France, Switzerland, Germany.
Company Characterization	**Size**	Tiago Lourenço owns the company together with Ricardo Araújo. During harvest time they employ about 10 workers.
	Age	The company started in 2007.
Waste Characterization	**Liquid (waste water)**	[Not Applicable]
	Solid (leaf, olive nut, twigs)	The pomace is composted together with the olive tree waste (from pruning and so on).
	Solid-liquid paste (bagasse)	Yes, the pomace.
	Amount produced	12 tons per year of bagasse approximately.
	Waste destination	Composting using olive pomace and pruning leaves.
Barriers	**Isolated area = More transportation required**	Limitation in moving the products because they are in a more isolated region and the transport costs are high.
	Market inefficiencies: lack of market infrastructure	they can't compete with the main brands. So they have a superior quality olive oil that has to be sold at a higher price and as such the preferred market is abroad.
Facilitators	**Funding**	Only this year will they have access to the European framework of funding for organic farming.
	Integrated, circular approach to composting	Sheep are fundamental in the approach to traditional olive groves because they end up controlling all the competing pasture to the olive grove in terms of water and mineral resources, at the same time that transforms it into assimilable manure, controls all the basal shoots (branches that remain on the trunk of the tree), are fundamental for soil regeneration.
	Sustainability-first mentality	They are a farm that is very open to receiving people who bring new perspectives and approaches that they reconcile with their own approaches...normally they always have a large base of thought currents related to sustainable and regenerative agriculture that are being used in other contexts and that they find interesting to adapt to their culture.
	High Interest in Innovation	Next year, the company in association with a company in Fundão that produces mushrooms will develop a technique called the Mycelium Net. The process is characterized by making a chip, i.e., the pruning is done, the chip machine goes to the place where the pruning was done and shreds all the pruning wood, which will remain at the base of the olive tree and then places mushrooms that will decompose the wood/substrate. The mushrooms will end up creating a communication network and symbiotic association (mycelium network) with the olive tree roots and is one of the soil recovery processes that the company is developing.