MONOGRÁFICO: La confluencia de Bioeconomía Circular, Biorrefinerías y Objetivos de Desarrollo Sostenible en el sector del olivar

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Resumen:

En este trabajo se revisan los conceptos básicos de Economía Circular, Bioeconomía y Biorrefinerías con un énfasis especial en el sector del olivar. La posibilidad de desarrollo de las biorrefinerías en este campo supone una serie de ventajas que inciden en los aspectos económicos, sociales y ambientales y, por tanto, pueden tener una traslación directa a conseguir los Objetivos de Desarrollo Sostenible (ODS). En este artículo se revisan cuáles son las principales contribuciones de las biorrefinerías basadas en la biomasa del olivar en los ODS, tanto desde el punto de vista industrial como desde el punto de vista de las cooperativas, que representan la gran mayoría de las estructuras productivas del olivar en España. Finalmente, se realiza un análisis de las barreras y oportunidades que pueden afectar a la consecución de los ODS en el ámbito de estudio.

Palabras clave: Bioeconomía Circular, Biomasa, Biorrefinería, Olivar, Objetivos de Desarrollo Sostenible.

MONOGRAPH: The confluence of Circular Bioeconomy, Biorefineries and Sustainable Development Goals in the olive sector

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Abstract:

In this work, the basic concepts of Circular Economy, Bioeconomy and Biorefineries are reviewed with a special emphasis on the olive sector. The possibility of developing biorefineries in this field entails a series of advantages that affect economic, social and environmental aspects and, therefore, can have a direct impact on achieving the Sustainable Development Goals (SDGs). This article reviews the main contributions of biorefineries based on olive biomass to the SDGs, both from the industrial point of view and from the point of view of cooperatives, which represent the vast majority of the productive structures in the olive oil sector in Spain. Finally, an analysis is carried out of the barriers and opportunities that may affect the achievement of the SDGs in the area of study.

Key Words: Biorefinery, Circular Bioeconomy, Olive biomass, Sustainable Development Goal.

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1. INTRODUCTION

According to the United Nations, the Sustainable Development Goals (SDGs) are a call for action by all countries – poor, rich and middle-income – to promote prosperity while protecting the planet. The 17 SDGs provide jointly a roadmap for humanity toward sustainable development.

SDGs can be clustered into three categories dealing with human well-being, sustainability and resources.

The progress to reach those Goals is measured by a relatively complex set of 232 indicators acting on 169 targets. For example, the SDG number 7 is called "Affordable and Clean Energy". For this goal, 5 targets have been selected, among them "ensure universal access to affordable, reliable and modern energy services by 2030"; this particular target will be monitored through these two indicators: "the proportion of population with access to electricity" "and the proportion of population with primary reliance on clean fuels and technology". A global indicator could be "renewable energy share in the total final energy consumption".

During the last few years, a great number of productive sectors have been analyzed to assess their contribution to the achievement of SDGs (Pizzi et al., 2020), but few of them are available in the scientific literature devoted particularly to the olive sector. The present work aims to present the potential contribution of olive tree cultivation, olive oil production process, and management of byproducts and residues to the achievement of SDGs, considering also the usual associated networks of olive oil producers (cooperatives). The relationship among the basic concepts of Circular Economy, Bioeconomy and Biorefineries and their application to the olive sector is also considered.

2. BASIC CONCEPTS: CIRCULAR ECONOMY, BIOECONOMY, AND BIOREFINERIES

The **circular economy** is a model of production and consumption, which involves: sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible (European Parliament, 2023). In this way, the life

cycle of products is extended. The European Commission defines the **bioeconomy** as "the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy" (European Commission, Directorate-General for Research and Innovation, 2012).

Taking both concepts, circular economy and bioeconomy, the **circular bioeconomy** focuses on the sustainable, resource-efficient valorization of biomass in integrated, multi-output production chains while also making use of residues and wastes and optimizing the value of biomass over time via cascading.

Summarizing all the definitions collected by Berntsson et al. (2012), the term **biorefinery** refers to a facility or industrial plant that integrates various physical, chemical and/or biological processes to convert biomass into a range of valuable products, including biofuels, chemicals, materials, and energy. The goal of a biorefinery is to maximize the efficient utilization of biomass resources and minimize waste by using a sustainable and environmentally friendly approach. Biorefineries offer diversified manufacturing processes to produce multiple valuable products from biomass to be the cornerstone in this holistic perspective.

Applied to the olive sector, the term biorefinery refers to the evolution of the traditional olive oil mill, where the conventional and unique product (olive oil) gives way to the possibility of obtaining multiple products, through the use of waste generated in the traditional process, such as pits, leaves, pomace, deffated olive pomace and even wastewater, towards a wide range of renewable products, including biofuels, bioenergy and renewable chemicals as well as materials (Romero-García et al., 2014).

Therefore, the concept of a biorefinery in general, and biorefineries based on olive-derived biomass in particular, is aligned with the principles of the circular bioeconomy, aiming to replace or complement traditional petroleum-based industries with sustainable and renewable alternatives, ultimately reducing reliance on fossil fuels and contributing to a more environmentally sustainable and economically viable future.

3. EXAMPLES OF CONTRIBUTION OF BIOREFINERIES TO SDGs

Table 1 shows some examples of how biorefineries or bioeconomy in general can contribute to different SDGs through relevant indicators. For example, one of the indicators for SDG number 1, No Poverty, is the "Proportion of population below the international poverty line"; biorefineries in general, but especially small-scale biorefineries (which is the usual case when considering the olive sector) can promote the development of entrepreneurship opportunities to produce incomes and jobs. Or for example, SDG number 6, "Clean water and sanitation" may be impacted because biorefineries can promote an increase in water-use efficiency to produce value-added products through mass integration.

Table 1. Examples of contribution of biorefineries to SDGs.

SDG	Indicator	How can biorefineries/ bioeconomy contribute
	1.1.1 Proportion of population below the international poverty line	Small-scale biorefineries can promote the development of entrepreneurship opportunities to produce incomes and jobs
	1.4.1 Proportion of population living in households with access to basic services	Biomass conversion into energy vectors is a promising option to strengthen access to heat and power in rural and urban areas in the future
	2.3.1 Volume of production per labor unit by classes of farming/pastoral/ forestry enterprise size	Bioeconomy can increase the production rates of agricultural products by implementing sustainable agriculture practices (e.g., decrease agrochemicals use)
	2.3.2 Average income of small scale food producers	Small-scale biorefineries are the way to increase the incomes of farmers due to the conversion of non-marketable agricultural products
	2.4.1 Proportion of agricultural area under productive and sustainable agriculture	Agricultural waste and agroindustrial waste valorization can increase the agricultural area to produce more income for farmers. Moreover, sustainable agriculture can be applied to decrease the use of agrochemicals
	6.4.1 Change in water-use efficiency over time	Biorefineries can promote an increase in water-use efficiency to produce value-added products through mass integration. Moreover, these facilities can be designed considering water cycles

SDG	Indicator	How can biorefineries/ bioeconomy contribute
	7.1.2 Proportion of the population with primary reliance on clean fuels and technology 7.2.1 Renewable energy share in the total final energy consumption	Biomass resources are generated all over the world to sustain biorefineries, which can provide biofuels and bioenergy using biomass as input
	9.3.1 Proportion of small-scale industries in total industry value-added	Small-scale processing of biomass sources can promote local employment and improve the socio-economic conditions of a rural zone through the commercialization of value-added products
	12.6.1 Number of companies publishing sustainability reports	Biorefineries can be associated with the industrial sector to valorize the by-products and wastes generated in the different production stages. The essence of biorefineries is to upgrade the raw material with a view towards sustainability

4. AGROINDUSTRIAL OLIVE BIORESOURCES

The production of olive oil involves the generation of different types of biomasses, both during the cultivation of olive trees and also during the production process of olive oil. First, olive trees are pruned yearly, generating a great amount of biomass. Olives, together with leaves that fall from trees and collected during harvesting, are taken to the olive mills, where leaves are separated and olives are washed, also generating a residual stream of wastewater that is taken to an aerial pond. Then, olives are crushed, and mixed and then olive oil is separated in the decanter, producing an oil stream, and separating the olive pomace.

Olive pomace is sent for recovery of the residual oil; first, crushed olive stones are separated, while the remaining pomace is dried and extracted, producing the olive pomace oil and the defatted (or exhausted) olive pomace dry residue.

The olive oil that was separated in the decanter is washed with water, also generating an additional wastewater stream, to finally obtain the virgin olive oil.

In summary, there are several kinds of bioresources available for biorefining, which are found in two different locations: the cultivation fields and the olive mills. First, in the fields, we find the biomass from pruning; and then, in the mills, we have

leaves, pits, the olive pomace, the residues of olive pomace after being extracted, and the wastewater generated.

As depicted in Figure 1, the University of Jaén is performing intense research on how to produce a wide range of products from all kinds of olive-derived biomass, including bioethanol, natural antioxidants, nanocellulose, oligosaccharides or ceramic materials, among others, in what we call the biorefinery based on olive biomass. Some contributions in reviews include the portfolio of bioproducts which can be obtained from olive biomasses and examples of biorefinery processes using these biomasses as raw materials (Contreras et al, 2020; Galán-Martín et al., 2022; Gómez-Cruz et al., 2023; Ruiz et al., 2017).

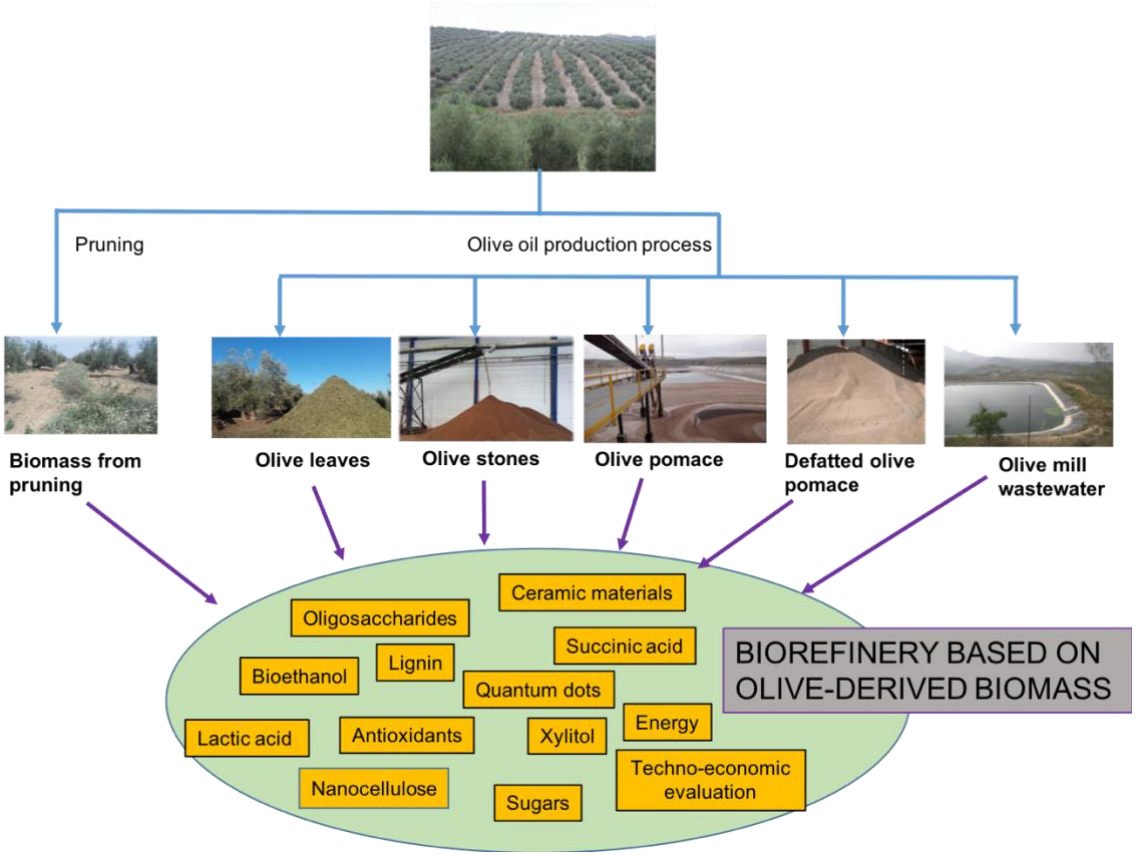

Figure 1. Basic scheme of the different types of olive biomass and main products obtained under the biorefinery approach.

After this introduction, we will call olive-based biorefineries to those industrial facilities that generate two or more bio-based products through sustainable cascading processing of olive biomass, and particularly, their portfolio will include bioenergy and/or biofuels.

5. POTENTIAL CONTRIBUTIONS OF OLIVE-BASED BIOREFINERIES TO SDGs

5.1 SDG-Indicators

The relationship existing between biorefineries, circular bioeconomy and the SDGs was recently reviewed by Solarte-Toro et al. (2021); in this article, the technical requirements, challenges, and perspectives of biomass are assessed. This analysis, initially applied to general biorefineries, can be particularized for the case of olive-derived biorefineries, as shown in Table 2.

Starting from the SDG number 1, no poverty, two main indicators are (1) the Proportion of population below the international poverty line and (2) the Proportion of population living in households with access to basic services. Biorefineries or bioeconomy, in general, can contribute respectively to achieving this SDG because small-scale biorefineries can promote the development of entrepreneurship opportunities to produce incomes and jobs, and Biomass conversion into energy vectors is a promising option to strengthen access to heat and power in rural and urban areas in the future.

When it comes to biorefineries that use olive biomass, they can provide job opportunities in biomass supply, logistics and conversion processes. Additionally, external heat and power consumption can be reduced by olive biomass conversion. These two facts can contribute to reducing poverty in this context.

Table 2. Potential contributions of olive-based biorefineries to SDGs achievement.

SDG	Indicator	How can olive-based biorefineries contribute
	1.1.1 Proportion of population below the international poverty line 1.4.1 Proportion of population living in households with access to basic services	Olive-based biorefineries may be a source of employment in biomass supply, logistics and conversion processes External heat and power consumption can be reduced by olive biomass conversion
	2.3.1 Volume of production per labor unit by classes of farming/pastoral/forestry enterprise size 2.3.2 Average income of small scale food producers	A fraction of olive pruning biomass is grindered and left in the cultivation fields as an organic amendment Incomes from pruning sale of biomass or crushed pits are expected from the biorefinery deployment

SDG	Indicator	How can olive-based biorefineries contribute
	2.4.1 Proportion of agricultural area under productive and sustainable agriculture	Several practices, such as crushing olive tree pruning biomass and spreading in the cultivation fields can contribute to sustainable agriculture
	6.4.1 Change in water-use efficiency over time	Water recovery systems from wastewater aerial ponds and reduction of water consumption in the olive oil production process are two ways of improving water efficiency in the olive oil sector Water integration in olive-based biorefineries will be crucial
	7.1.1 and 7.1.2 Proportion of population with access to electricity and Proportion of population with primary reliance on clean fuels and technology	Renewable energy from olive-derived biomass can be produced under different schemes/products: bioethanol, biogas, electricity, and renewable chemicals
	9.3.1 Proportion of small-scale industries in total industry value-added	A big proportion of olive oil mills are small-scale processing of biomass facilities, which can promote local employment and improve the socio-economic conditions of a rural zone through the commercialization of value-added products

Moving on to SDG 2, No Hunger, Table 2 summarizes that the implementation of sustainable agriculture practices and the increase of incomes of farmers are two ways to move towards the attainment of this SDG. In the case of olive-derived biorefineries, the usual practice of leaving a portion of olive pruning biomass in the fields as an organic amendment can contribute to the sustainability of the cultivation; moreover, farmers can expect an increase in their income by selling biomass or olive pits that are widely used as biofuels.

As a last example from Table 2, one of the most relevant SDG related to the biorefineries based on olive biomass, is SDG #7, Renewable Energy, because energy is probably the most direct application of biomass; moreover, in addition to heat, a number of indirect products related to energy can be produced from olive pits or olive pruning biomass, among other raw materials; these products include bioethanol, biogas or electricity.

In conclusion, many of the olive-derived biomass biorefineries can have an impact and contribute to achieve most of SDGs, as can be summarized in a brief sentence, Table 3.

Table 3. Potential effects of olive-based biorefineries in achieving selected SDGs

SDG	Effect from olive-biorefineries
1 No poverty	Job creation in collection, transport, conversion of biomass materials. Income increase by selling of pruning biomass, olive pits or leaves
2 Zero hunger	Increased food production can be derived from the use of composting or organic amendement with olive residues
5 Gender equality	Half of olive groves are owned by women
6 Clean Water	Water use improvement and reuse
7 Affordable and Clean Energy	Electricity and heat can be obtained from renewable olive-derived residues
8 Decent Work and Economic Growth	New ways of valorization of olive-derived biomass will result in economic growth in rural areas
9 Industry, Innovation, and Infrastructure	Machinery adaptation, process development, product separation and so on will lead to innovations in industry and technological development
11 Sustainable Cities	Renewable energy and renewable biobased products will lead to more sustainable communities
12 Responsible Consumption and Production	Olive biomass valorization can be a driver for the sustainability of olive oil production to reach targets like the sustainable management and efficient use of natural resources and the reduction of waste generation
13 Climate Action	Environmental issues and climate action are tightly connected to olive derived biomass collection and transformation, representing an alternative more environmental friendly disposal method

5.2 The impact of cooperativism in the olive oil sector on SDGs

The studies and discussion around the SDGs have had an increasing impact in recent years, both in terms of research on the SDGs and its influence in companies (Pizzi et al. 2020). In this regard, studies focusing on the role of the sustainable development goals and olive oil cooperatives companies, indicate that olive cooperatives are social economy enterprises or entities, which base their decisions and management on the farmers who make up these enterprises. This is a model of shared management that influences the welfare and sustainability of the territory, considering that in the olive oil sector in Spain, cooperative firms accounts for 66% of the total olive oil production, which indicates that this management model implies the development of the Spanish olive oil industry in its majority (Mozas-Moral, 2019; Parrilla and Ortega, 2022).

Olive-growing cooperatives are increasingly using management models based on social innovation, focusing on the development of innovative strategies to generate added value among farmers. These social innovations include the management of diversifying activities, such as tourism (olive oil tourism), the efficient management of waste or by-products such as olive pits, pomace, or the optimisation of water resources (Sánchez-Martínez et. al., 2020).

Similarly, the size of these companies means that sustainability and equality plans are implemented, which orients personnel and employment generation policies towards the fulfilment of SDGs. Also, the attraction of talent and the commitment of these industries to more innovative technologies such as Smart olive oil mill or olive oil mill 4.0, generate a more efficient use of resources in the industry and increase the productivity of these industries. The implementation of the SDGs in these entities (Table 4) implies the transition from systems focused almost exclusively on production and distribution to new paradigms whose objectives include environmental, nutritional, and ethical objectives (Antonelli et. al, 2020).

Table 4. Contribution of olive oil cooperative companies to the SDGs achievement

SDG	SDG Description	Impact on olive oil cooperatives
	Zero Hunger. The food and agriculture sector offers key solutions for development, and is central for hunger and poverty eradication	Olive oil cooperatives can manage production of more olive oil as foodstuffs
	*Good Health and Well-Being.* Ensuring healthy lives and promoting the well-being for all at all ages is essential to sustainable development	Production of sustainable and healthy foods such as olive oil
	*Quality Education.* Obtaining a quality education is the foundation to improving people's lives and sustainable development	Olive oil cooperatives promote a compulsory education and promotion fund in their annual accountability
	*Gender Equality*. Gender equality is not only a fundamental human right, but a necessary foundation for a peaceful, prosperous and sustainable world	Olive oil cooperatives fight against depopulation, ageing and the gender gap by promoting generational change and sustainability and gender equality plans

SDG	SDG Description	Impact on olive oil cooperatives
	*Affordable and Clean Energy*. Energy is central to nearly every major challenge and opportunity	Olive oil cooperatives develop clean energy, promotion of integrated production agriculture and green covers
	*Decent Work and Economic Growth*. Sustainable economic growth will require societies to create the conditions that allow people to have quality jobs	Olive cooperatives facilitate territorial development, local employment and the development of global markets thanks to their cooperative dimension
	*Industry, Innovation, and Infrastructure*. Investments in infrastructure are crucial to achieving sustainable development	Olive cooperatives develop large infrastructures that require a high level of innovation to compete in global markets
	*Responsible Consumption and Production*. Promote a responsible consumption in consumers	Olive oil cooperatives promote the consumption of sustainable, ecological and healthy agriculture through the development of environmentally friendly early harvest oils and extra virgin olive oils
	*Climate Action*. Climate change is a global challenge that affects everyone, everywhere	Olive cooperatives develop programs against climate change and the use of water waste and its recycling, as well as the circular economy
	*Life on Land*. Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss	Olive oil cooperatives slow down the deterioration of the vegetation cover and help to preserve the culture, society, economy and green ecosystems in the territory
	*Partnerships*. Revitalize the global partnership for sustainable development	Olive oil cooperatives maintain an important stakeholders policy

6. BARRIERS AND OPPORTUNITIES

There are some barriers that hinder the development of biorefineries based on olive biomass, and there are also some opportunities. Table 5 presents the corresponding SWOT matrix, where the main points of weakness, strengths, opportunities, and threats are summarized.

Table 5. SWOT matrix associated with the development of olive based-biorefineries

WEAKNESS	**THREATS**
• Small and scattered farms • Seasonality of the resource • Need to adapt machinery for collection. • High transport cost, depending on the distance. • Need for development of conversion technologies. • Lack of organization for biomass exploitation	• Competition from other renewable resources • Large uncertainties around costs and environmental impacts. • Lack of support instruments for the production, transformation, and use of biomass
STRENGTHS	**OPPORTUNITIES**
• Growing social support for sustainable initiatives • Growing importance of renewable energies in energy policies • Contribution to environmental sustainability in energy production (reduction of CO_2 emissions, • Creation of jobs, direct and indirect, and diversification of income for the rural population • Long-term economic advantages in home heating due to cheaper prices of biomass compared to fossil fuels	• Energy needs in rural areas. • Possibility of using the biomass mixed with other energy or environmentally recoverable products. • Possibility of use in cogeneration, for thermal uses and electricity production • The policies of the European Union and many other countries recognize the need to support and promote the bioenergy sector. • Role of biorefineries coupled with carbon capture and storage to provide carbon dioxide removal and reach carbon neutrality.

Jointly, future biorefineries in our region should be developed taking into account the integral use of olive biomass feedstock, to meet circular bioeconomy, making full use of their availability and considering seasonality. It should ensure market opportunities for bioproducts, considering both demands and competition with their counterparts. As an advantage, biorefineries based on olive biomass are of the second generation; as not compete with food uses, they help mitigate concerns about diverting food resources for biofuel production and face energy demand, while reducing the competition for arable compared to first-generation biorefineries based on corn or sugarcane.

According to Arias et al. (2023), one of the main bottlenecks in the development of a biorefinery scheme is the technical and economic feasibility, the integration of mass and energy flows, together with the optimization of resource use. For example, cogeneration could be a technology to promote thermal use and electricity production efficiently. Although it can increase capital costs, it may enhance the sustainability of the biorefinery (Hernández et al., 2014), a goal to reach sustainable development. Although there are obstacles along the way,

research and innovation on biorefinery will promote the best scenarios to balance sustainability, circularity, economic viability, and energy efficiency, key aspects to contribute and comply with the SDGs.

The potential to integrate the biorefinery process with carbon capture and storage technology can further enhance global decarbonization efforts, even potentially achieving carbon-negative emissions (Galán-Martín et al., 2022). Improvement and innovation in catalysts, enzymes, and microorganisms with higher capacity and application may favour more efficient, sustainable, and economical bioprocesses in the biorefinery (Igbokwe et al., 2022).

Arias and coworkers (2023) conclude that biorefineries need government support, policies, and market share with regulations and sustainable brand certification to increase market opportunities compared to the product's counterparts. These could be instruments for the change. In the case of Spain, there have been developed specific instruments (regulations, plans, etc.) for the Circular Economy and the Bioeconomy, which can be key in terms of the reduction and valorisation of olive biomass (Duque Acebedo et al., 2022) and envisioning SDGs targets. In this line, projects like ATRESBIO aimed at promoting value chains to obtain bioproducts derived from biomass, in this case, olive biomass generated in Andalusia was one of the targets (ATRESBIO, 2023). There are some instruments, but investment and competitiveness will be crucial to promoting and diversifying sustainable biorefineries able to bring a wide range of chemicals, energetic products, etc. to reach SDGs. Other important issue is that olive oil cooperatives and other local industries are pillar to promote olive-based biorefineries. These new multiproduct-industries should fulfil the industrial necessities (energy/electricity, waste management, new income for farmers, sustainability, etc.) of the others. Adequate divulgation and knowledge transfer and innovation activities in its territorial environment could be crucial success to join forces of all involved actors. An example could be the BioRefine Denmark, expected to produce protein, along with other biobased-products, for satisfying feed requirement of farming industries, which were promoters of the project (NIRAS, 2023).

7. CONCLUSIONS

Biorefineries have a crucial role as industrial facilitators to promote circularity and sustainability in the agroindustrial sector, such as in the olive oil production chain and associated industrial tissue. Bio-based production in biorefinery based on olive biomass may help fulfil SDGs targets (e.g., contributing to SDGs numbers 1, 5, 7, 8, 9, 11, 12, and 13) and there are indicators to measure the performance. Nevertheless, technical and economic limitations must be overcome, along with other weaknesses and threats. In this scenario, not only researchers but also Government, investors, cooperatives, and citizens should be practitioners in the transition from a linear and fossil-fuel-based economy to a circular bioeconomy based on bioresources, like olive biomass.

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