SCALE UP
community-driven
bioeconomy development

Task 2.3 Regional Biomass and Nutrient Availabilities in Andalusia, Spain

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Abbreviations

A	Andújar
AR	Ash Rejection
CC	Cover Crop
CEC	Cation Exchangeable Capacity
COMP	Composted
EOP	Extracted olive pomace
Ha	Hectare
km	kilometres
ktoe	Thousand tonnes of oil equivalent
Mha	Megahectare
MJ	Megajoule
MSW	Municipal Solid Waste
Mt yr-1	Metric Tonne Per Year
MW	Megawatt
NCOMP	Not Composted
O	Olvera
OL	Olive leaves
OM	Olive Mill
OMWW	Oil mill wastewater
OTP	Olive tree pruning biomass
P	Phosphorus
R	Reja
SA	Stables Aggregates
t	Tonne
T	Tobazo
TC	Total C
TN	Total N
toe	Tonne of oil equivalent
WHC	Water Holding Capacity

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1.1 Introduction

1.1.1 Background

Andalusia is a region located in the southwest of Europe with an area of more than 87,000 km² (ca. 9Mha) and 940 km of coastal area. The agricultural area represents about 4.4 Mha and the forestry area is about 4.6 Mha. This makes it the fourth-largest region in the European Union in terms of surface area and the most populated region in Spain, with some 8,400,000 inhabitants. Andalusia has historically been an agricultural region, in comparison with the rest of Spain and the rest of Europe. The primary sector constitutes an important source of employment due to the link between people and environment, as 51% of the population lives in rural areas where resources are mainly produced.

With around 350,000 farmers (Dawson, 2022) and 5,400 agro-industrial businesses (S3P T&BD, s.f.), Andalusia ranks second in Europe for agricultural production, accounting for about 23% of all agri-food jobs in Spain.

In terms of agricultural biomass, there is substantial potential for biomass (extensive areas of olive groves, fruit, and vegetables in the region). Specifically, (CIRCE, 2016):

- Considering only agriculture, biomass production reaches 8 million tons a year, highlighting sectors such as olive groves (29%), horticulture (18%), wheat straw (13%), and corn straw (5%).
- The biomass potential amounts to 3,955 ktoe[1], of which 1,322 is agricultural waste, 77 ktoe is livestock waste,1,023 industrial waste, 322 forestry waste, 620 ktoe from energy crops and 591 ktoe is from urban waste.
- Other interesting waste streams include paper and pulp, sewage sludge, plastics, and MSW (waste).
- For horticultural and forestry waste streams, there are less advanced conversion options operational in Andalusia.

Olive cultivation is mainly located in the Mediterranean basin, providing an important socio-economic value to the areas where it is grown. Andalusia is leader in the sector (Caracterización del sector agrario y pesquero de Andalucía., 2022):

- Area: 1.64 million hectares in 2022 (60% of the national area, 32% of the EU area, and 13% of the world area). Between 2018 and 2022 it has increased by 2.7%.
- Holdings: 165,431 holdings where the predominant crop is olive groves.
- Production: 6.56 million tonnes of olives (2020/21). Between the 2016/17 and 2020/21 campaigns, production has increased by 13.7%.

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[1] ktoe: 1 ktoe = 1000 toe. Toe: Tonne(s) of oil equivalent, is a normalized unit of energy. By convention, it represents the estimated quantity of energy that may be produced from one tonne of crude oil. It is a standardized unit with a net calorific value of 41,868 kilojoules/kg.

1.1.2 Scope

Spain is the world leader in terms of surface area, production, and foreign trade. Spanish olive oil production accounts for 70% of EU production and 45% of world production (Blasco, 2023). The sector is not only of undeniable economic importance, but also has important social, environmental, and territorial implications. More than 350,000 farmers are engaged in olive growing, the sector supports some 15,000 jobs in the industry (Dawson, 2022).

The olive grove area in Spain covers 2.75 million hectares, with 2.55 million hectares dedicated to olive oil mills (93% of the total olive grove). This crop is present in 15 of the 17 autonomous communities, with Andalusia producing the most with 1.67 million hectares (The olive tree: Spain’s treasure, 2022).

Table 1 shows the distribution of the olive grove area in Andalusia in 2022:

Table 1: Distribution of olive grove area in Andalusia *(Caracterización del sector agrario y pesquero de Andalucía., 2022)*.

Province	Surface (Ha)	%
Jaen	582,114	35.5
Cordoba	374,703	22.9
Seville	255,610	15.6
Granada	200,089	12.2
Malaga	140,084	8.5
Huelva	34,362	2.1
Cadiz	33,402	2.0
Almeria	19,262	1.2
Andalusia	1,639,627	100.0

According to data from the 2020/2021 campaign, Andalusia produced 6.56 million tonnes of olives, with 42.3% harvested in the province of Jaen, 24.8% in Cordoba, and 14.8% in Seville. Between the 2016/17 and 2020/21 campaigns, the percentage of production devoted to olives for oil mills averaged 92.6%, while that dedicated to olives for table consumption was 7.4%. (Caracterización del sector agrario y pesquero de Andalucía., 2022)

The following image shows the provincial distribution of the average production (t) of olives from oil mill (image A) and table olives (image B) for the 2016/17 to 2020/21 campaigns.

Fuente: AICA

Figure 1: Average production of olives for oil mill and table olives (2016/17-2020/21) *(Caracterización del sector agrario y pesquero de Andalucía., 2022)*.

The total value of olive oil and olive production amounted to 3,468 million euros in Andalusia in 2021, of which 2,212 million euros (63.8%) corresponded to olive oil, while the remaining 1,256 million euros (36.2%) were olives. Olives include table olives (11.3%) and mill olives processed by industries (24.9%) (Caracterización del sector agrario y pesquero de Andalucía., 2022).

Systems of olive cultivation:

There are 3 main systems of olive cultivation:

- Traditional: traditional olive groves consist of spaced rows of huge, centuries-old olive trees, which are mainly established on steep slopes where it is difficult to mechanise the work. This type of agriculture has a major drawback in that productivity is typically limited due to the low number of olive trees per hectare. On the other hand, traditionally, harvesting is done by hand, a model that is changing as the rural world becomes more professionalized.
- The intensive olive grove: this type of plantation allows an increase in the density of olive groves per hectare and practically all the tasks are mechanised. The yields improve considerably due to the use of irrigation systems and mechanised harvesting.
- Superintensive olive grove: the olive trees are arranged in the form of a hedge in this type of plantation. The superintensive olive grove has had an unprecedented increase in recent years because it allows a high level of mechanisation and rapid entry into production. However, this type of crop is highly dependent on the water conditions of the soil (if it is rainfed, production is considerably reduced).

Table 2 shows the different characteristics of the different production systems.

Table 2: Characteristics of different production systems in Spain *(Pérez, 2023)*.

Characteristics of different production systems.

Type of olive grove	Density (olive trees/ha)	Area (%)	Production (kg olives/ha)
Traditional	< 140	51	7 000
Intensive	141-1000	46	10 000
Superintensive	>1001	3	12 000

The most common production systems in Spain are traditional (51%), followed by intensive (46%). Intensive systems require a higher initial investment since the number of trees per hectare is higher than in traditional systems. However, intensification makes it possible to increase productivity while lowering unit production costs, resulting in a shorter payback period: 7 years in superintensive versus 13 years in traditional plantations (Pérez, 2023).

Specifically, in Andalusia, 81.3% of the olive grove area is classified as traditional, 13.6% as intensive, and 2.5% as superintensive based on planting density. The following figure (Figure 2) compares the trend of the different production systems in Spain and in Andalusia (Caracterización del sector agrario y pesquero de Andalucía., 2022).

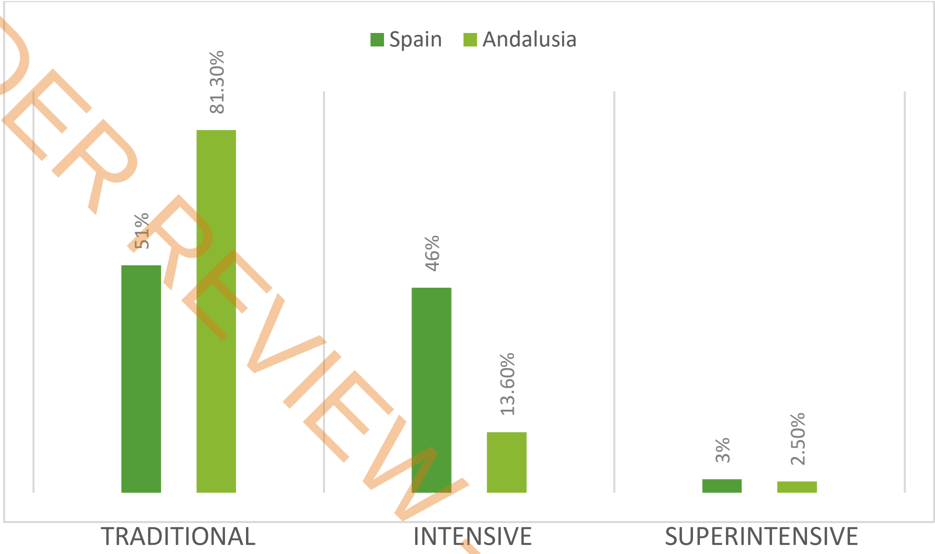


Figure 2: Comparison of the different production systems. Source: Own elaboration.

1.2 Biomass Availability

1.2.1 Location of olive biomass

In Andalusia, more than 8.7 million tonnes of biomass resources are generated each year from agriculture, of which 2.5 million tonnes correspond to the olive sector (Caracterización del sector agrario y pesquero de Andalucía., 2022).

Regarding the olive oil value chain, biomass is found in three different locations or phases (Table 3): Agricultural (Olive Farmland), olive oil mill, and Olive-Pomace or oil extraction plant (Contreras, Romero, Moya, & Castro, 2020). The biomass potential of the olive industry in Andalusia can be calculated as 2.5 Mt per year in agriculture, 4.2 Mt per year in olive-oil mills (Caracterización del sector agrario y pesquero de Andalucía., 2022) and 1,6 Mt per year in pomace olive oil extraction businesses (Polonio, Villanueva, & Gómez-Limón, 2022) (Table 3).

Table 3: Biomass potential of the olive grove sector in Andalusia (t/year)

Phase	By-product	Biomass (t/year)
Agricultural (Olive Farmland)	Pruning residues (wood, branches, and leaves)	2,548,258
Olive-Oil Mill*	Olive Pomace	4,212,348
	Stone	
	Olive mill leaves	
Olive-Pomace or oil extraction plant	Stone	1,592,716
	Extracted pomace	

1. Olive Farmland “Biomass from pruning”: Every year, biomass from pruning is created in the agricultural fields; historically, the unproductive branches from each tree are removed biennially to facilitate fruit collection during the next crop. This procedure generates a considerable amount of biomass, which must be removed from the fields as quickly as possible to prevent the spread of plant pests.

2. Olive-Oil Mill “Biomass from olive mills”: Other types of biomasses can be found in olive mills, where olives are transported to make olive oil. First, olives are cleaned in the mill, where a blowing machine separates leaves and short thin branches (olive mill leaves). The crushed olives are then centrifuged to generate olive oil and olive pomace.
   In some small mills, the conventional hydraulic pressing separation technology is still employed, although in most cases, continuous centrifugation systems are used. Two types of olive pomace are produced depending on the function of the decanter used for centrifugation:
   2.1 Two-phase pomace (from the two-phase decanter): The by-product is Olive Pomace (“Alperujo”). “Alperujo” is a very wet semi-solid substance (water content between 65-70%). Its composition is made up of a liquid residue (“Alpechín”) and a solid residue (pomace) (Muñoz, 2011).
   2.2 Three-phase pomace (from three-phase decanter): The by-product is pomace (“Orujo”). Pomace is a wet solid, with a water content of around 45%. The pomace consists of a combination of skin, pulp, stone, and fatty residue (Muñoz, 2011).

   Figure 3 shows each of the systems and the associated by-products:

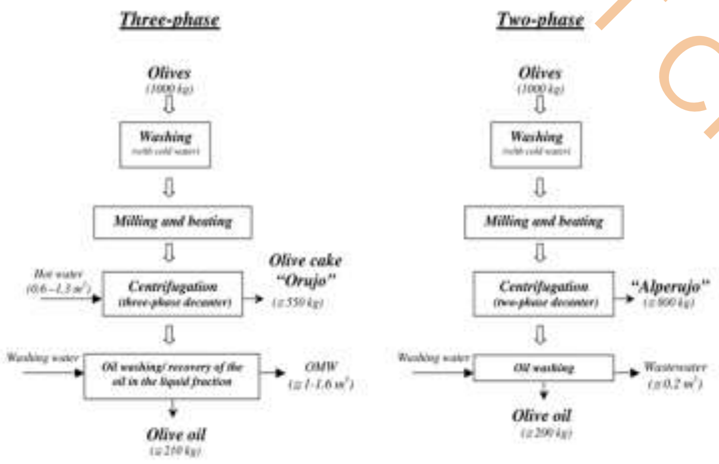


Figure 3: Comparison of the three and two-phase centrifugation systems for olive oil extraction *(Alburquerque J. , Gonzálvez, García, & Cegarra, 2004)*.

Almost all Spanish mills (99%) utilize a two-phase decanter to separate the oily paste into two phases (oil phase and pomace) without adding water. This reduces the generation of wastewater and, therefore, the pollutant load compared to three-phase decanter pulps and the traditional pressing method.

However, others insignificant methods of processing olive oil exist as well. For example, destoning the olives before grinding them is one such method. Although its effects on the quality of olive oil are still unknown, this may support the future valorisation of olive stones and seeds. Recently, an innovative two-phase decanter (multiphase decanter) containing wastewater, oil (8–12%), and olive pulp was introduced to the market. It produces both a dehydrated peel and a unique semi-solid pitted olive cake, known as "pate" or "pate olive cake" (Contreras, Romero, Moya, & Castro, 2020).

3. Olive-Pomace or oil extraction plant: To extract the remaining oil that is still present in the pomaces, they are often sent to pomace extraction factories. Technical hexane, a combination of alkanes, is the most often employed solvent in this solid-liquid extraction technique used in these facilities to extract residual oil. Crude pomace oil and an extracted pomace by-product are the results of this method. To obtain olive pomace oil, crude pomace oils are delivered to oil refinery facilities (García-Martín et al., 2020).

Figure 4 summarises the different processing schemes and by-products obtained in the production of olive oil:

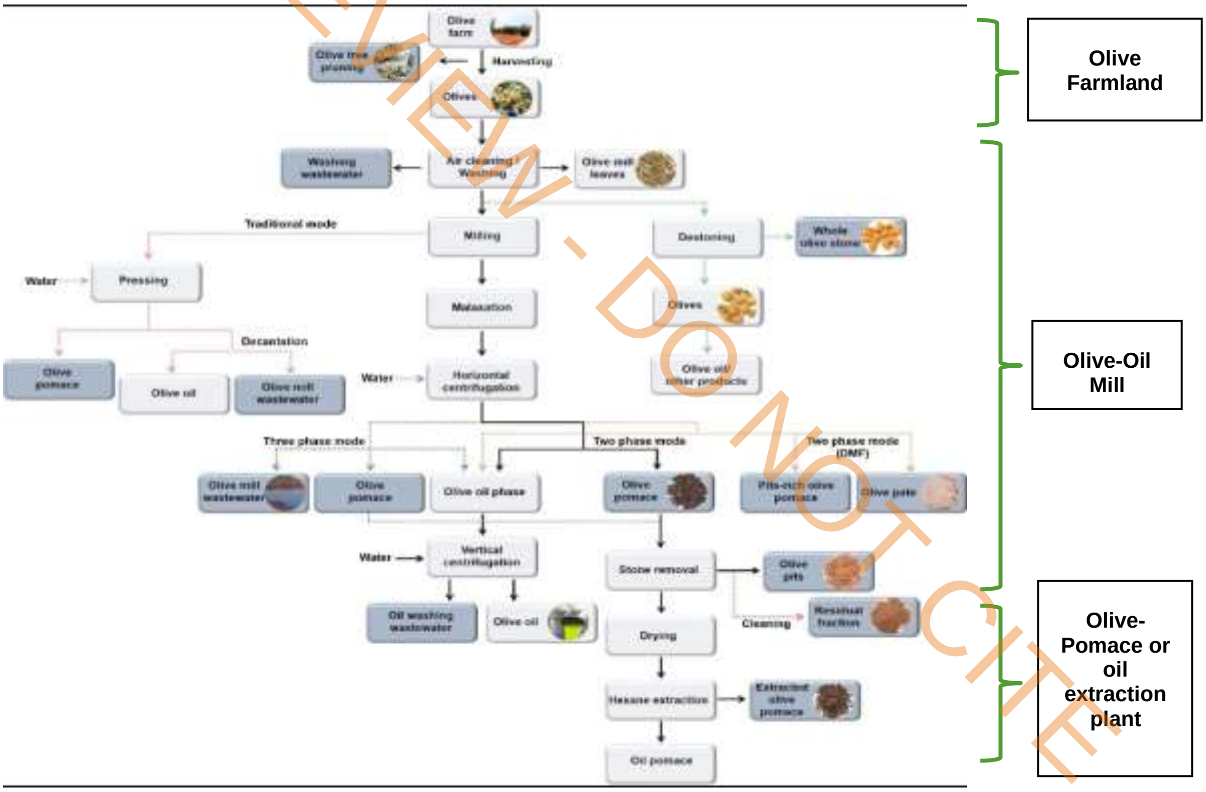


Figure 4: Simplified processing schemes for olive oil production and by-products produced *(Contreras, Romero, Moya, & Castro, 2020)*

The most important by-products derived from the olive value chain can be defined as follows (Polonio, Villanueva, & Gómez-Limón, 2022):

1. **Olive Leaves** that is a mixture of leaves and small branches from the prunings of olive trees as well as the harvesting and cleaning of olives before oil extraction from olives. Olive leaves are generally used for direct combustion, animal feed (fresh), or pellet manufacturing. About half of the farmers eliminate the prunings by controlled burning in the field that produces CO_2, and particulate emissions and poses a potential fire risk. A potential and important use of pruning is to protect the soil and improve soil quality.
2. **Olive Stone**: Olive stone is a lignocellulosic substance that contains significant levels of protein, phenolic chemicals, cellulose, and hemicellulose. It is one of the most important solid by-products generated from olive oil production.
3. **Olive Pomace** is the main residue of the oil extraction process currently used in practically all the olive mills in Spain, the so-called two-phase system. This residue represents about 80% of olive weight and consists of olive skin, pulp, seed, and fragments of stones, as well as a small amount of residual oil, between 1% and 3%, depending on the process conditions and olive variety. It is a highly polluting waste due to the elevated organic matter and phenolics content, as well as difficult to dispose of since it has a high moisture content of 60-80% (Manzanares, et al., 2017). The olive pomace is one of two major by-products of the olive oil extraction industry, for every 100 kg of olives, 40 kg of olive pomace (highly variable depending on technology) (Berbel & Posadillo, 2018).
4. Currently, the most widely used practice for olive pomace is to treat the residue in extracting industries where it is dried and extracted with hexane to recover any residual oil that is commercialized as pomace olive oil after chemical refining. **Extracted olive pomace**: the final solid residue generated in pomace olive oil extracting industries after pomace oil recovery, extracted olive pomace, usually has ~ 10% moisture and contains residues of pulp, seeds, skins, and stones (Manzanares, et al., 2017). The proportion of stone in extracted olive pomace depends on the upstream extraction processes since frequently part of the stones is removed either in the mill or in the pomace olive oil extracting industry itself.
5. **Olive oil mill wastewater** is a by-product of the three-phase processes of olive oil extraction from olives. This black liquid effluent has a high concentration of phenolic chemicals from the vegetative water of the olive fruit, the water used for washing and treatment, and a portion of the olive pulp and waste oil (Ben Sassi, Boularbah, Jaouad, Walker, & Boussaid, 2006). Some research has demonstrated the possibility of treating this wastewater through different processes such as composting, use as fertiliser, and for microbial growth that will reduce its toxicity and produce a reusable stream of treated water.

Table 4 shows, for each of the by-products obtained in the olive oil industry, the main intrinsic characteristics of the by-product that are important for the valorization process, the current valorization options and the economic value of the by-products (University of Jaén (UJA), Olive Tree Institute (IO), Ankara University (AU), Olive Research Institute (ORI), & Direction Générale de la Production Agricole (DGPA), 2018).

Table 4: Olive oil industry by-products generated in different stages of the value chain.

	OLIVE LEAVES	OLIVE STONE	OLIVE POMACE (2-PHASES)	OLIVE POMACE (3-PHASES)	OLIVE OIL MILL-WASTEWATER (3-PHASES)
Location	Olive grove	Olive mill	Olive mill	Olive mill	Olive mill
Production Rate	2.5-3.0 t/ha	90-100 kg/t of olives	650-750 kg/t of olives	550 kg/t of olives	650-1200 L/t of olives
Ash content (%,ar)	3-5	0.5-2	2-5	2-5	-
Moisture, (%,ar)	15-20	30-35	65-70	45-50	55-70
Lower Heating Value (MJ/kg)	16-18	17-19	16-18	16-18	-
Selling price (€/kg)	Free	0.08 (wet)	Disposal Fee	Disposal fee	-
Current valorisation	None (burn at the field)	Sell to biomass producers (at low price)	Extractor companies	Extractor companies	Fertilizer (in some cases)

1.2.2 Use of olive by-products

In Andalusia, olive by-products are often used as a source of energy. It is used less frequently to produce compost and animal feed, and less frequently to produce products with significant added value (Table 5).

Table 5: Use of olive by-products *(Berbel, Gutiérrez-Martín, & La Cal, Valorización de los subproductos de la cadena del aceite de oliva, 2018)*.

Use of olive by-products		Percentage
Energy generation	Electricity generation	47.00%
	Thermal energy	33.00%
Composting or direct field application		14.30%
Waste		0.70%
Animal feed		5.00%

Due to their composition and characteristics, the by-products generated by olive cultivation and its associated industries can be vaporized in different applications.

Energy

Due to this biomass potential, Andalusia has developed a map of resources and facilities that encompasses two applications in one tool: the biomass potential in Andalusia and the biomass facilities in Andalusia.

The tool has functionalities common to both, such as information by municipality, where a single search shows all the information regarding potential and existing facilities in a selected municipality; and specific functionalities for each application, such as the search for biomass in a given quantity and the search for facilities in a given location.

Biomass Potential in Andalusia gathers updated and extended information on the potential of this energy resource, analysing sectors not previously studied and updating biomass production ratios as a consequence of the application of the information obtained in the biomass field. Currently, there is no official register of biomass production that collects, for each of the producing sectors, the quantities of biomass generated. This means that the estimation of its potential requires the availability and handling of reliable and contrasted information, as well as calculation methods capable of evaluating it as closely as possible (Agencia Andaluza de la Energía (AAE), 2022).

The figure (Figure 5) below shows that biomass potential is predominant throughout the province of Jaen, where potential values are between 5,001-10,000 (toe/ha) and 10,001-15,000 (toe/ha). For the rest of Andalusia, biomass potential is mostly concentrated in the southern area of Seville and Cordoba, with predominant values between 5,001-10,000(toe/ha). (Agencia Andaluza de la Energía (AAE), 2022).

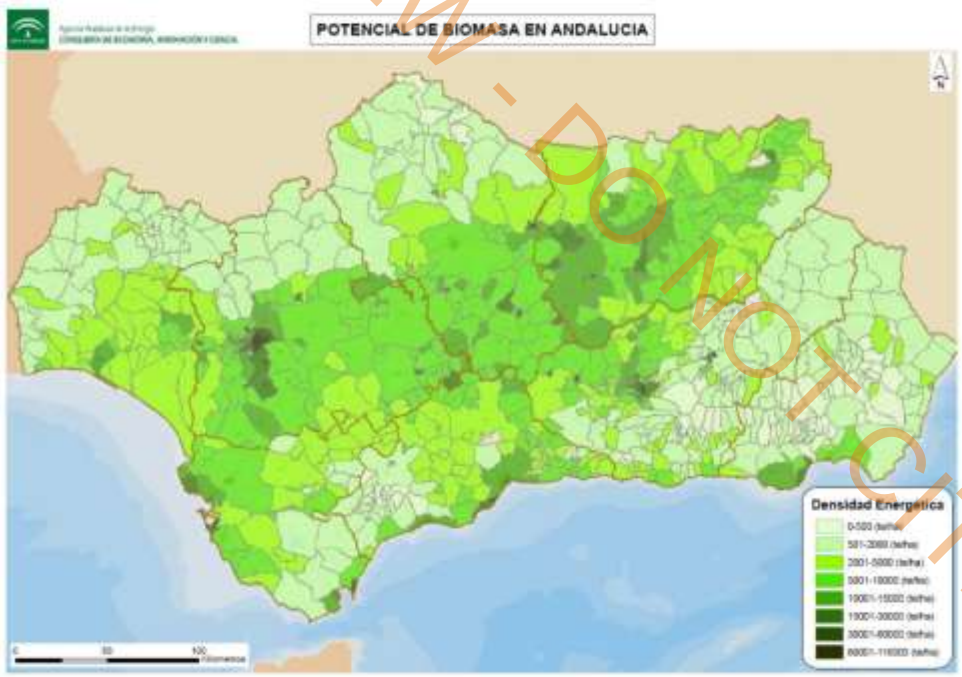


Figure 5: Biomass Potential in Andalusia *(Agencia Andaluza de la Energía., 2020)*.

The map of biomass installations in Andalusia, shows all the installations that use biomass as fuel for electrical or thermal use, or that generate fuel from biomass, such as biofuel and pellet factories. For the first time, information that until now was dispersed in different registers and applications, is unified in one tool. The information on this map is updated periodically and highlights the possibility of being able to consult in each municipality the installations for thermal use with biomass, for all sectors, classifying the information according to the type of equipment; being of great use to both installation companies and biomass distributors (Agencia Andaluza de la Energía (AAE), 2022).

The following table (Table 6) shows the evolution of biomass applications for electricity capacity in Andalusia:

Table 6: Annual evolution of biogas and biomass electricity generation in Andalusia (MW) *(Consejería de Política Industrial y Energía, 2022)*

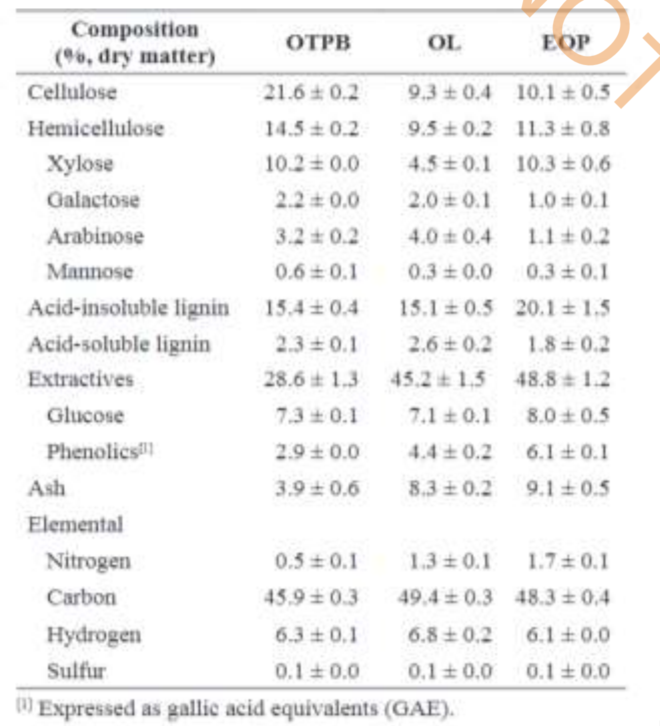
ANDALUSIA	2014	2015	2016	2017	2018	2019	2020	2021
Biogas electricity generation	29.82	29.82	30.75	30.75	31.53	33.45	33.45	33.45
Biomass electricity generation	257.48	257.48	257 .48	257.48	227.98	273.98	273.98	273.98
TOTAL	6114.58	6119.34	6123.42	6124.66	6103.91	7215.81	8103.4	8940.82

Table 6 shows that in 2021, 33 MW or 0.4% of renewable energy in Andalusia came from biogas and 274 MW or 3% came from biomass electricity generation.

Biofuels

Olive by-products are often used as a source of energy. However, other potential uses are possible, such as their transformation into bioethanol for use as advanced biofuel. Biofuels are defined as sustainable and renewable energy sources derived from biowaste. In this sense, as lignocellulose-derived biomass materials, olive tree pruning biomass (OTPB), olive leaves (OL) and extracted olive pomace (EOP) residues contain a certain proportion of carbohydrate polymers and lignin that could be converted into fermentable sugars and other valuable molecules, which in turn would function as precursors for high value-added products such as biofuels (Table 7).

Table 7: Chemical characterization of olive tree pruning biomass, olive leaves, and extracted olive pomace. Results are expressed as g/100g raw material oven dry weight (Manzanares, et al., 2017)**.**



Composition (%, dry matter)	OTPB	OL	EOP
Cellulose	21.6 ± 0.2	9.3 ± 0.4	10.1 ± 0.5
Hemicellulose	14.5 ± 0.2	9.5 ± 0.2	11.3 ± 0.8
Xylose	10.2 ± 0.0	4.5 ± 0.1	10.3 ± 0.6
Galactose	2.2 ± 0.0	2.0 ± 0.1	1.0 ± 0.1
Arabinose	3.2 ± 0.2	4.0 ± 0.4	1.1 ± 0.2
Mannose	0.6 ± 0.1	0.3 ± 0.0	0.3 ± 0.1
Acid-insoluble lignin	15.4 ± 0.4	15.1 ± 0.5	20.1 ± 1.5
Acid-soluble lignin	2.3 ± 0.1	2.6 ± 0.2	1.8 ± 0.2
Extractives	28.6 ± 1.3	45.2 ± 1.5	48.8 ± 1.2
Glucose	7.3 ± 0.1	7.1 ± 0.1	8.0 ± 0.5
Phenolics[1]	2.9 ± 0.0	4.4 ± 0.2	6.1 ± 0.1
Ash	3.9 ± 0.6	8.3 ± 0.2	9.1 ± 0.5
Elemental			
Nitrogen	0.5 ± 0.1	1.3 ± 0.1	1.7 ± 0.1
Carbon	45.9 ± 0.3	49.4 ± 0.3	48.3 ± 0.4
Hydrogen	6.3 ± 0.1	6.8 ± 0.2	6.1 ± 0.0
Sulfur	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0

[1] Expressed as gallic acid equivalents (GAE).

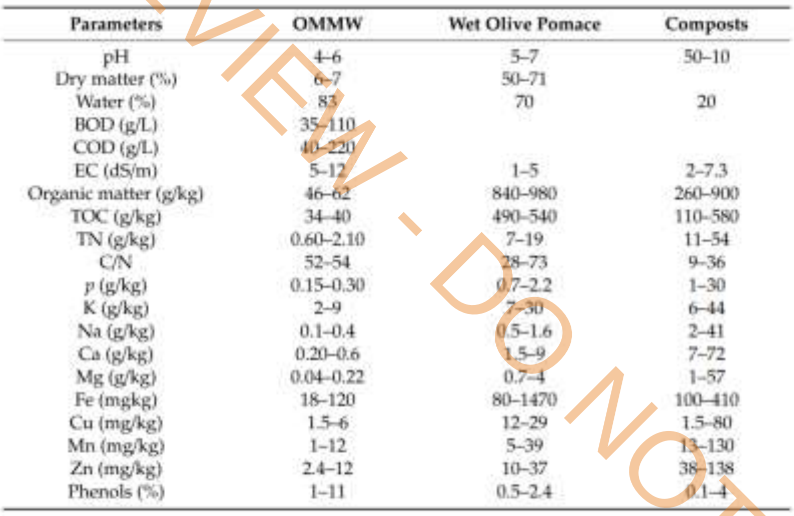
High-added value compounds

On the other hand, olive biomass as a source of bioactive compounds, is a priority in applied research in this field. The study carried out by (Galanakis & Kotsiou, 2017) describes the different technologies for the recovery of bioactive compounds from olive oil, processing olive by-products, and suggests a comprehensive methodology to ensure the sustainability of the process.

Wastewater from mills is a rich source of bioactive compounds and natural phenols such as hydroxytyrosol, tyrosol, and oleuropein. These phenols are active ultraviolet filters used in cosmetics (Galanakis C. M., 2017). The most widely used technique consists of carrying out a pretreatment of the initial material and the subsequent conversion of oleuropein into hydroxytyrosol, prior to the extraction of phenols with a solvent and/or other technologies.

The separation and purification of these high-added value compounds could open the door to future research, given the inhibitory effect that phenolic compounds can have on sugar fermentation. The removal of these compounds from the aqueous extract could also favour the production of ethanol from the glucose present in the extractive fraction, thus increasing the production of biogas or bioethanol (Manzanares, et al., 2017).

Table 8: Chemical Composition of oil mill wastewater (OMWW) from a 3-phase extraction process *(Alburquerque J. , Gonzálvez, García, & Cegarra, 2004)*.



Parameters	OMMW	Wet Olive Pomace	Composts
pH	4–6	5–7	50–10
Dry matter (%)	6–7	50–71	
Water (%)	83	70	20
BOD (g/L)	35–110		
COD (g/L)	40–220		
EC (dS/m)	5–12	1–5	2–7.3
Organic matter (g/kg)	46–62	840–980	260–900
TOC (g/kg)	34–40	490–540	110–580
TN (g/kg)	0.60–2.10	7–19	11–54
C/N	52–54	28–73	9–36
p (g/kg)	0.15–0.30	0.7–2.2	1–30
K (g/kg)	2–9	7–30	6–44
Na (g/kg)	0.1–0.4	0.5–1.6	2–41
Ca (g/kg)	0.20–0.6	1.5–9	7–72
Mg (g/kg)	0.04–0.22	0.7–4	1–57
Fe (mgkg)	18–120	80–1470	100–410
Cu (mg/kg)	1.5–6	12–29	1.5–80
Mn (mg/kg)	1–12	5–39	13–130
Zn (mg/kg)	2.4–12	10–37	38–138
Phenols (%)	1–11	0.5–2.4	0.1–4

Table 8 indicates that phenolic compounds are present in higher concentrations in oil mill wastewater (OMMW) than in wet olive pomace and compost. It is possible due to the hydrophilic nature of these compounds that allows them to be soluble in the aqueous fraction and less soluble in the oily (hydrophobic) phase.

Because of its high content of phenolic compounds (10,650 mg/L), strong disagreeable odor, high concentration of fats, oil, and grease (FOG), and high organic loading (COD and BOD5), oil mill wastewater has a reddish-black appearance. About 400 times more organic material is present in this effluent than in regular home wastewater. Oil mill wastewater also has an electrical conductivity (EC) range between 5.5 and 12.0 dS/m, a pH between 4 and 5, and a high content of polyphenols (Khdair & Abu-Rumman, 2020).

Animal feed and human nutrition

Moreover, there are other medium-value uses of olive biomass, such as animal feed, in which case the most widely used by-product is olive pomace. The study carried out by (Zabetakis & Nasopoulou, 2013) of the available evidence on the use of olive by-products as feed in aquaculture and livestock concluded that, in both cases, olive pomace consumption low 12% of intake does not affect growth and improves the fatty acid profile in both meat and milk. In ruminants with a diet with a pomace content below 10 % of total intake, a reduction in feed cost is achieved and milk composition is improved (with no negative effect on milk production).

Finally, reference is made to the by-products of the olive oil chain as a functional feed supplement to improve human nutrition. As mentioned above, the consumption of olive pomace improves the fatty acid profile of both meat and milk by decreasing the composition of saturated acids and increasing unsaturated acids. In addition, a common finding is that the fat and solids content of milk, as well as its yield, increase on a diet containing olive pomace.

Biorefinery or bioindustry

Biorefineries are defined as structures where biomass conversion processes take place to produce chemicals, fuels, energy, and high-value-added products from biomass. In rural areas with a high density of agricultural and agro-industrial wastes, such as olive crop areas and related industries, an integrated biorefinery process based on lignocellulosic feedstock is particularly attractive.

To determine the feasibility of biorefineries, an important question to address is to analyse what kind of products can be obtained, distinguishing between "tractor" and "gregarious" products.

- Tractor products:

  Tractor products are those which justify the collection and transport of biomass in the first instance, and which justify the industrial investment for its subsequent management:

  - Primary tractor products: Products for direct consumption or subjected to a first transformation.
  - Secondary tractor products: Products from the valorisation of by-products generated in the production of primary tractor products.

- Gregarious products:

  Products obtained from the same biomass that are processed to obtain tractor bioproducts, but which do not in themselves justify the total investment necessary for their management: collection, transport and logistics, storage, processing plant, etc (Quintela & Pinilla, 2019).

Table 9 summarises a classification of the tractor and gregarious bioproducts that can be obtained from olive trees in Andalusia. Bioproducts of particular interest are highlighted in bold.

Table 9: Main tractor and gregarious bioproducts from an agricultural olive biorefinery in Andalusia *(Quintela & Pinilla, 2019)*.

BIOMASS	BIOPRODUCTS
Olive tree	PRIMARY TRACTOR PRODUCTS: **Olive oil** SECONDARY TRACTOR PRODUCTS: **Olive pomace oil** **Bioenergy (biofuels, heat and electricity)** GREGARIOUS PRODUCTS: Sterols, Triterpene alcohols, Aliphatic alcohols, Waxes, Saturated aliphatic hydrocarbons **Squalene** Tocopherols **Phenolic compounds** (hydroxytyrosol, oleuropein, oleocanthal) **Triterpenic compounds** (maslinic acid, oleanolic acid, ursolic acid...) Fermentable carbohydrates Lignin, cellulose, and hemicellulose Proteins and amino acids Organic acids

1.3 Nutrient Availability

1.3.1 Nutrient requirements

The olive tree is adapted to the Mediterranean climate, characterised by hot, dry summers with low rainfall and high inter- and intra-annual variability. This adaptation means that it is not particularly demanding in terms of water and nutrients. However, intensification of olive orchard management entails increased use of fertilizers, especially nitrogen, phosphorus, and potassium.

The nutrient requirements of the olive tree are as follows:

- **Micronutrients:** those which the plant needs in smaller quantities (Iron, Aluminium, Boron, Chlorine, Nickel, Chlorine, Sodium, Cobalt, Manganese, Zinc, Fluorine, Copper, Molybdenum and Selenium).
- **Macronutrients:** which are extracted in larger quantities (Potassium, Nitrogen, Calcium, Phosphorus, Sulphur, and Magnesium).

Most of these nutrients are absorbed through the roots, although most organs (leaves, fruit, trunk, etc.) are capable of absorbing nutrients in ionic form when they are in solution. The aim of fertilisation is to supplement with the essential elements that the olive grove needs and not to add to the soil or the tree all the elements that the tree needs, as many of them are found in the soil in adequate quantities. These quantities differ from one soil to another for various reasons (previous treatments, cultivation techniques, etc.), and the requirements vary with the age of the olive grove, its productive characteristics, etc. It is, therefore, necessary to determine the nutritional needs of the olive grove and to predict the amount of fertiliser required annually to achieve optimum productivity, which depends on several factors:

1. Knowledge of the available nutrient content and diagnosis of toxicities caused by excess salts (sodium, chlorine, and boron).

2. Foliar analysis: This consists of the chemical analysis of a sample of leaves from the tree. It allows the detection of low nutrient levels before the onset of harmful deficiencies.

Table 10 shows an interpretation of nutrient levels in olive leaves expressed in dry matter.

Table 10:Interpretation of nutrient levels in olive leaves expressed in dry *(López Clemente, 2021)***.**

Element	Deficient	Appropriate	Toxic
Nitrogen (%)	1.4	1.5-2.0	-
Phosphorus (%)	0.05	0.1 -0.3	-
Potassium (%)	0.4	> 0.8	-
Calcium (%)	0.3	>1	-
Magnesium (%)	0.08	> 0.1	-
Manganese (ppm)	-	> 20	-
Zinc (ppm)	-	> 10	-
Copper (ppm)	-	> 4	-
Sodium(%)	-	-	> 0.2
Chlorine (%)	-	-	> 0.5
Boron (ppm)	14	19-150	185

The nutritional needs of the olive grove are lower than those of other crops, it can produce fruit even in adverse conditions for other crops, and it has nutrient reserve organs that are easily reusable (reserves contained in old stems and leaves) (López Clemente, 2021).

1.3.2 Olive fertilisation

Some of the alternative soil management practices are spontaneous or cultivated cover crops (CC) along the inter-rows of olive trees which prove to be an effective tool to reduce erosion, run-off, and loss of soil fertility. Most olive growers use spontaneous vegetation because of the economic savings on seeds. In 2018, 92% of the Spanish olive grove areas with some form of CC had spontaneous CC, sometimes combined with pruning residue cover crops, which are long-lasting, protect the soil and improve soil fertility. However, the continued use of the same CC produces a change in the ruderal flora. CC have a significant role in increasing soil organic matter and nutrients (Rodríguez-Lizana, Repullo Ruibérriz de Torres, Carbonell-Bojollo, Moreno-García, & Ordóñez-Fernández, 2020).

In general, the nutrient absorption capacity through the leaves is relatively low, which is why foliar fertilisation is recommended, as there is experimental evidence that, in rainfed olive groves, foliar fertilisation is a very effective system for supplying nutrients. Foliar application of fertilisers is therefore indicated in those cases where the application of immobilised or blocked nutrients with limited availability in the soil is required or when conditions may lead to a loss of these nutrients (Hidalgo, Leyva, Hidalgo, Pérez, & Vega, 2020)

In irrigated olive groves, the usual way of applying fertilisers is by fertigation; however, foliar fertilisation is a complement to this technique and allows correcting the demand for nutrients at certain specific times.

Not all nutrients are well absorbed by the leaves of the olive tree. Nitrogen (N), Sodium (Na), and potassium (K) are very well absorbed, and phosphorus (P) has a very acceptable absorption. However, the high uptake of sodium (Na) and chlorine (Cl), which is negative for the olive tree, must also be considered. Foliar uptake rate of Calcium (Ca), and Iron (Fe) is very low, a nutrient deficiency that must be corrected by soil inputs or fertigation (Table 11).

Table 11: Absorption of nutrients through the olive leaf *(Hidalgo, Leyva, Hidalgo, Pérez, & Vega, 2020)*.

Foliar absorption	Nutrient element
Very high	Sodium (Na), Potassium (K) and Nitrogen (N)
High	Phosphorus (P), Chlorine (Cl), and Sulphur (S)
Low	Magnesium (Mg), Zinc (Zn), Copper (Cu), Manganese (Mn), Molybdenum (Mo) and Boron (B)
Very low	Iron (Fe) and Calcium (Ca)

Other factors that participate in the absorption of nutrients through the olive leaf are:

- Application at times of high ambient humidity or at night improves nutrient uptake by keeping the leaf surface moist for longer.
- High temperatures and low relative humidity: reduced uptake due to evaporation of water and formation of salts from the respective fertilisers on the leaf surface.
- Reducing the fertiliser concentrations in the treatment mixture and increasing the number of applications per year leads to better results.

1.3.3 Nutrient recycling

Olive orchard sustainability may benefit from the recycling of trimmed orchard material, olive pomace, and olive mill effluent, as well as the use of recycled wastewater for irrigation. However, there is a risk of environmental damage.

- Olive-tree pruning is a lignocellulose material and, therefore, is mainly composed of cellulose, hemicellulose, and lignin. The literature contains very little information about the elemental composition. Nonetheless, some authors point out that elemental composition of the olive-pruning debris is: 44-46% C, 6% H, 47% N, and 0% S. When pruning residues are incinerated, almost all of their N content is volatilised (P and K would remain mostly available). However, when pruning residues are shredded, an amount of N is retained on the farm that would be available in the medium to long term (due to the relatively low decomposition rate of pruning residues) (Liétor Gallego, García Ruiz, & Domouso De Agar, 2023).

- The rate of decomposition of olive leaves is relatively slow due to their high lignin and polyphenol content and their high carbon: nitrogen ratio, i.e. the availability of these nutrients will be medium to long term.

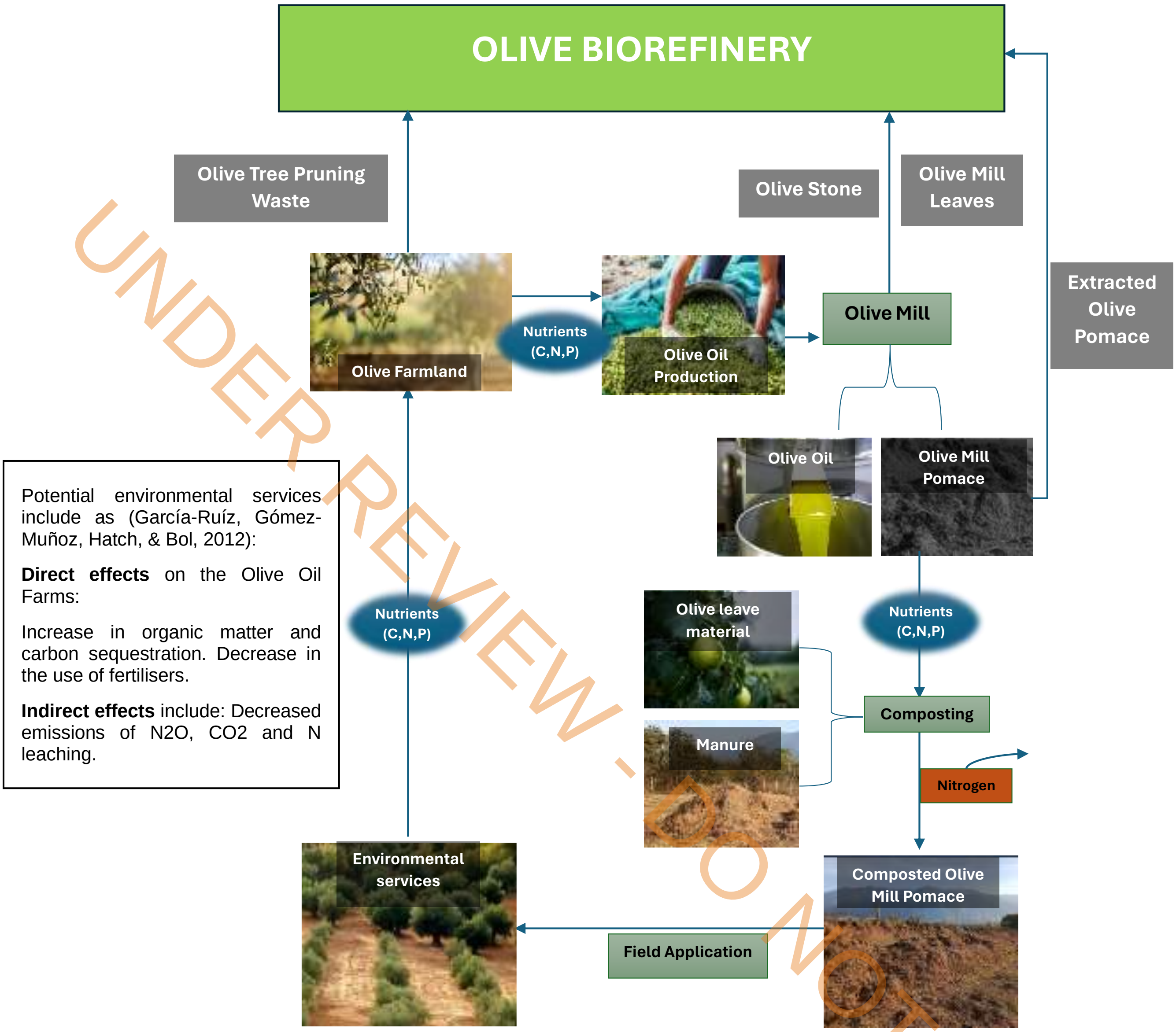
- About 30.000 t of olive stones are produced annually by the olive table business (Khdair & Abu-Rumman, 2020). As a lignocellulose material, its main components are cellulose, hemicellulose, and lignin (García-Martín et al., 2020). Owing to its elevated lignin concentration, it was purportedly appropriate for thermal application. Compared to other lignocellulose materials, olive stones were discovered to offer a great potential as solid biofuel for combustion.

  However, it has also been suggested that it can be used as a source of fermentable sugars, antioxidants, and other lignocellulose materials. Environmental pollution will be substantially reduced if olive stones can produce added-value products from thermochemical and biochemical perspectives.

  Sulfur can hardly be found in olive stones in terms of elemental makeup. Chlorine and copper stand out among the several trace elements that are present, with concentrations ranging from 90 mg/kg to 435 mg/kg and from 0.6 mg/kg to 2.3 mg/kg, respectively. Ash levels are frequently lower than 2% (wt.). Olive stone ash mostly contains the inorganic components Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, and SiO_2 (García-Martín et al., 2020).

- For years, olive mill wastewater application was tested under field conditions as an organic amendment. Many times, the results concerning the raise of plant growth, crop yields, and enhancement of soil fertility were promising, while in some other cases phytotoxicity problems, groundwater contamination, decreased soil porosity, as well as enhanced electrical conductivity, salinity, increased soil acidity and decreased N mineralization rate occurred (Chatzistathis & Koutsos, 2017).

- Recycling of olive mill pomace through composting could be a strategy for providing some ecological services to olive oil groves. Figure 6 shows the C, N and P cycling of fruits harvested in olive oil farming when olive mill pomace is composted and applied to olive oil groves.



Potential environmental services include as (García-Ruíz, Gómez-Muñoz, Hatch, & Bol, 2012):

Direct effects on the Olive Oil Farms:

Increase in organic matter and carbon sequestration. Decrease in the use of fertilisers.

Indirect effects include: Decreased emissions of N2O, CO2 and N leaching.

Figure 6: Fate of C, N, and P of the fruit harvested in the olive oil farming when olive mill pomace is composted and applied to the olive oil groves. Source: Own elaboration

Firstly, composting olive mill pomace reduces most of the potential environmental pollution problems related to the disposal of approximately 4 million tonnes of olive mill pomace produced in Andalusia over a relatively short period (3 months). On the other hand, most of the nutrients (especially nitrogen, phosphorus, and potassium) harvested with the yield, are contained in the olive mill pomace, and therefore after composting and application to olive oil groves help to recycle these nutrients, reducing the need for chemical fertilisers. The estimates show that between one to two-thirds of the Andalusian olive, oil groves could be fertilised annually with the olive mill pomace produced in Andalusia after composting, with a subsequent reduction of about 25 – 60% in chemical fertilisers. In addition, the main beneficiary of the economic and environmental profits of composting olive mill pomace and application to olive oil groves is the farmer (García-Ruíz, Gómez-Muñoz, Hatch, & Bol, 2012).

Table 12 shows an analysis of different properties of olive receiving (COMP) or not (NCOMP) composted olive mill pomace at four Andalusian olive oil mills (Olvera (O), Reja (R), Tobazo (T) and Andújar (A)) (García-Ruíz, Gómez-Muñoz, Hatch, & Bol, 2012).

The addition of olive mill pomace compost improves each of the measured parameters, indicating an improvement in the quality of soil qualities for cultivation without the use of chemical fertilisers.

Table 12:Analysis of different properties of olive farms receiving (COMP) or not (NCOMP) composted olive pomace from olive oil mills *(García-Ruíz, Gómez-Muñoz, Hatch, & Bol, 2012)*.

Site		WHC (%)	SA (%)	CEC (meq100 g^{-1})	LOI (%)	TC (%)	TN (%)	Available P (µg P g^{-1})
O	COMP	26.3 ± 0.81^{a}	51.8 ± 2.0^{a}	22.2 ± 1.22^{a}	3.95 ± 0.95^{a}	2.29 ± 0.39^{a}	0.25 ± 0.04^{a}	10.6 ± 0.04^{a}
	NCOMP	22.3 ± 0.3^{b}	34.0 ± 1.6^{b}	20.8 ± 0.21^{b}	3.45 ± 0.85^{a}	2.00 ± 0.49^{a}	0.27 ± 0.03^{a}	9.3 ± 0.03^{a}
R	COMP	21.8 ± 1.3^{a}	57.9 ± 1.8^{a}	25.3 ± 3.83^{a}	8.34 ± 3.67^{a}	4.84 ± 1.90^{a}	0.29 ± 0.03^{a}	30.3 ± 0.03^{a}
	NCOMP	20.5 ± 1.7^{b}	37.1 ± 0.9^{b}	18.6 ± 0.27^{b}	3.96 ± 1.09^{b}	2.30 ± 0.57^{b}	0.23 ± 0.02^{a}	11.5 ± 0.02^{b}
T	COMP	23.6 ± 0.5^{a}	56.7 ± 0.2^{a}	21.1 ± 3.46^{a}	6.31 ± 2.22^{a}	3.66 ± 1.15^{a}	0.25 ± 0.08^{a}	6.9 ± 0.01^{a}
	NCOMP	20.5 ± 0.8^{b}	22.6 ± 0.6^{b}	15.4 ± 2.06^{b}	2.39 ± 0.62^{b}	1.39 ± 0.32^{b}	0.10 ± 0.02^{b}	7.6 ± 0.02^{a}
A	COMP	30.2 ± 0.5^{a}	23.9 ± 1.0^{a}	23.3 ± 6.9^{a}	16.1 ± 3.49^{a}	8.49 ± 2.11^{a}	0.74 ± 0.33^{a}	57.4 ± 0.33^{a}
	NCOMP	28.7 ± 1.3^{a}	23.7 ± 1.5^{a}	10.6 ± 1.2^{b}	1.88 ± 0.41^{b}	1.09 ± 0.21^{b}	0.05 ± 0.02^{b}	3.57 ± 0.02^{b}

Water holding capacity (WHC), soil stables aggregates (SA), cation exchangeable capacity (CEC), organic matter (LOI), total Carbon (TC), total Nitrogen (TN), and available Phosphate.

1.4 Discussion of the Result

To sum up:

- In Andalusia, the olive industry is regarded as both a vital component of the region's cultural legacy and a strategic driver of job and revenue growth.
- Olive oil manufacturing and olive pruning produce massive waste streams.
- Nutraceuticals, bioenergy and biofertilizers, biobased materials, food and feed additives, and other new value-added and commercially viable ingredients and products could be created from these olive waste and by-products.
- Olive mill pomace is primarily composted and then applied back to the farm by olive growers to recycle nutrients taken after harvest.

1.5 Conclusions

Most of the biomass derived from olive groves in the EU Mediterranean basin are produced in Spain, accounting for around 51% of pruning residues, 72% of leaves, olive stones, and extracted pomace, 81% of olive pomace and 28% of wastewater. (Galán-Martín, et al., 2022).

Figure 7 shows by-products obtained from olive orchards and olive mills:

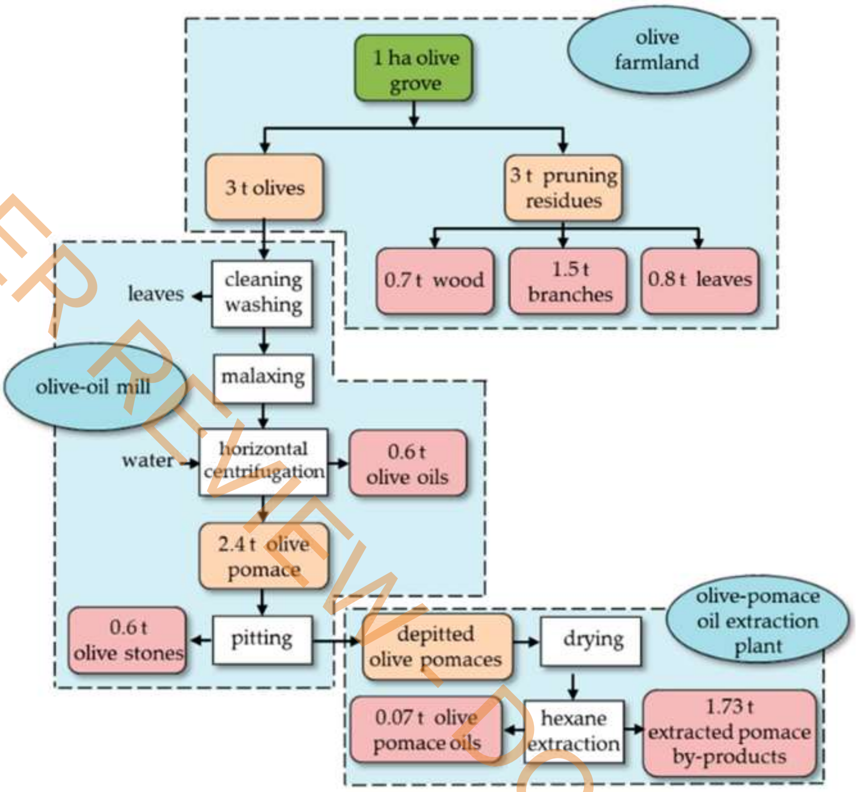


Figure 7: By-products obtained from olive orchards and olive mills *(García-Martín et al., 2020)*

Table 13 shows the biomass potential in Andalusia based on the data provided in Figure 7 “By-products obtained from olive orchards and olive mills” and the estimated distribution of olive grove in Andalusia.

Table 13:Olive-derived biomass potential in Andalusia.

Region	Distribution (ha olive grove)	Tonnes (t)							
		Olives	Pruning Residues	Leaves	Olive Oils	Olive Stones	Olive Pomace	Olive Pomace Oils	Extracted Pomace By-Products
-	1.0	3.0	3.0	0.8	0.6	0.6	2.4	0.07	1.73
Andalusia	1,639,627	4,918,881	4,918,881	1,311,701.6	983,776.2	983,776.2	3,935,104.8	114,773.89	2,836,554.71

		Metric Tonne (Mt)							
Andalusia	1,639,627	4.9	4.9	1.3	1.0	1.0	3.9	0.1	2.8

Olive grove and their industry associated involve distinct procedures, like cutting branches and wood from pruning, removing leaves, washing olives, grinding, pounding, and extracting the oil. As a result, huge quantities of by-products are generated (stones, leaves, pomace...). Particularly, olive pomace (OP) causes environmental problems, and one way that has been found to manage its negative impact is its use as a soil fertility improver. Studies such as (Alaoui, El Ghadraoui, Tanji, Harrach, &

Farah, 2023) indicate that while improving soil structure, they do not modify soil pH and salinity and simultaneously increase organic matter and plant nutrient availability. Moreover, it has been demonstrated that the incorporation of these organic residues into the soil improves the structural stability index of the aggregates and facilitates the aggregation of soil particles, which is especially important in soils with low levels of organic carbon (Figure 8).

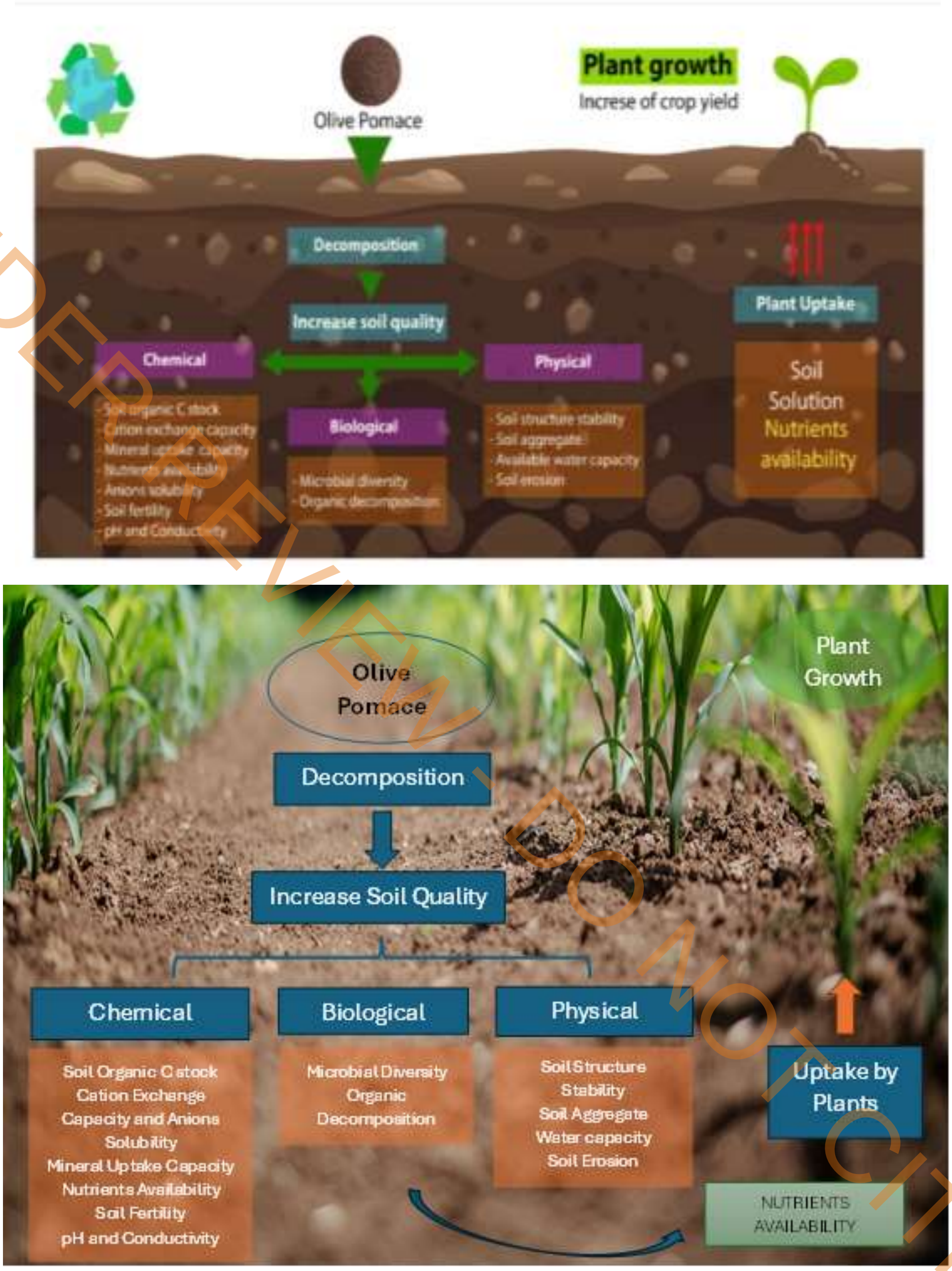


Figure 8: Olive pomace as a sustainable bio-fertiliser *(Alaoui, El Ghadraoui, Tanji, Harrach, & Farah, 2023)*.

Traditionally, pruning waste has been burned without any purpose. But for the past few years, this method has been coupled with ground deposition and shredding as an organic input. Firewood is either consumed by the farmers themselves or marketed without much-added value. Industrial by-products such as the stone or pomace have also traditionally been used as fuels for thermal purposes and the leaf has been used as livestock feed or for compost production together with fatty and wet pomace and residues from livestock farms (Berbel, Gutiérrez-Martín, & La Cal, Valorización de los subproductos de la cadena del aceite de oliva, 2018).

However, it can be shown that olive grove biomass has been used mostly for energy, to a smaller amount for animal feed and compost production, and very seldom for obtaining products with higher added value. Current research focuses on biomass as a way to obtain high-value-added products, such as bioethanol as a second-generation fuel or bioplastics, among others.

A biorefinery integrated process based on lignocellulosic feedstock is particularly appealing in rural regions with large levels of agricultural and agro-industrial waste, such as olive crop areas and associated businesses. More than 70% of all olive waste produced in Spain is accumulated in the Andalusian area, which includes the municipalities of Jaen, Cordoba, and Seville. As a result, the valorization of these wastes is interesting from a social and environmental perspective.

1.6 Recommendations

Recommendations to improve biomass availability and nutrient recycling in the olive sector in Andalusia are:

- Improve regulatory cohesion at regional, national, and European level.
- Create business plans for regionally suitable biobased solutions.
- Provide training on regulations for public administration, private enterprise, and citizens.
- Develop incentives for companies that work with bioactive products.
- Promote research. Innovative bio-based products demand intensive R&D work. Public-private research consortia should be encouraged in this regard.
- Engage stakeholders with experience in bioproduct uses, in de biorefinery design.
- Promote communication and exchange of experience and know-how between research and value chain actors.
- Promote SME-engagement. Bioeconomy companies in the region are often of low to medium size, with limited financial resources.

For the SCALE-UP- project and the multi-actor platform it is recommended:

- To strengthen and continue the innovation support programme for bio-based solutions. These are in line with key policy objectives, the European Green Deal, the EU Bioeconomy Strategy, the EU's long-term vision for rural areas, and the EU Rural Pact and Action Plan.
- To strengthen and continue the training program addressing nutrient recycling, primary producer integration into value chains, digitalization, efficient infrastructures and logistics, social innovation, governance, and trade-off strategies.
- To enhancing dialogue and cooperation among actors in the value chain.
- To address in the support and training programme the regulatory developments regarding by-products and end-of-waste status (see below).

B*y-products and and-of-waste status*

The industrial biomass category includes organic waste generated in the agri-food, fishing, and forestry industries. Most of the by-products generated by these industries should not be considered waste, since they usually have an alternative use in the market as raw materials that find applications in other industries or sectors.

This can be considered the main obstacle, since in the new bioeconomy framework, for many of these biomasses to be reused in other circuits (e.g., food or pharmaceutical), they must reach the end of waste status. Some of these biomasses have already begun the process of achieving this status. According to the "Law 7/2022 of 8 April on waste and contaminated soils for a circular economy[2] a substance or object that results from a production process and whose purpose is not the production of that substance or object is considered as a by-product and not as waste when the following conditions are met:

- There is no doubt that the substance or object is meant for future usage.
- The substance or object can be used directly without further processing other than normal industrial practice.
- The material or item is created as an intrinsic element of a manufacturing process. The further use complies with all relevant product requirements, as well as with the protection of human health and the environment, without causing overall adverse impacts on human health or the environment.

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[2] Law 7/2022 of 8 April on waste and contaminated soils for a circular economy.

For a substance or object to be considered as a by-product, these conditions must be fulfilled simultaneously, i.e. only if every one of them is met will it be a by-product, otherwise the applicable legal regime will necessarily be that of waste (Agencia Andaluza de la Energía., 2020).

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