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ASSESSING THE POTENTIAL OF OLIVE RESIDUES FOR ENERGY VALORIZATION IN WESTERN ANDALUSIA

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Abstract

Utilisation of waste biomass is crucial for tackling the current energy crises and meeting the different targets set for it, from a global to a regional level, as highlighted in the United Nations 2030 agenda for sustainable development. To achieve these goals, proposals must be established to enable the use of local waste biomass as a source of clean and sustainable energy.

Another key aspect of this transition includes the recent commitment to green hydrogen as a substitute for fossil fuels. Hydrogen is a compound that has already been used in industry for decades (e.g., refineries), which guarantees i) the existence of a current demand and ii) a know-how that guarantees a certain degree of confidence for the large-scale use of this vector.

To unify both aspects, this work addresses the analysis and quantification of agricultural residues, specifically from olive industry, and its possible potential to produce green hydrogen in Western Andalusia. Therefore, this study helps providing the basis for the implementation of a roadmap for the decarbonisation of the selected area using local biomass sources.

The results obtained show that hydrogen generation can reach a peak of up to 592.2 tonnes in the month of January from biomass waste from the olive industry, highlighting the great potential of this residues in Western Andalusia and providing a new perspective for the future development of bioenergy in the region.

Keywords: Agricultural residues; waste management; energy valorisation; Geographical Information Systems

1. Introduction

Today's growing demand for energy, largely met by non-renewable fossil fuels, has led to a damaging climate and an increasingly shortage of resources. This fact, combined with more stringent policies for the use of renewable resources, has made the development of an energy model based on clean energy sources to reduce greenhouse gas emissions one of the major challenges of recent years (Kim et al., 2021).

Given this framework, one of the most promising options that has gained special interest in recent years is the use of green hydrogen as an energy vector. It can be produced from renewable sources, such as solar, wind or biomass (as shown in Figure 1), while at the same time solving one of the major problems normally associated with the use of renewable energies: the variability of production. This is because hydrogen functions as a substance that stores energy and subsequently allows it to be released in a controlled manner, thus decoupling supply from demand (Dopson et al., 2022).

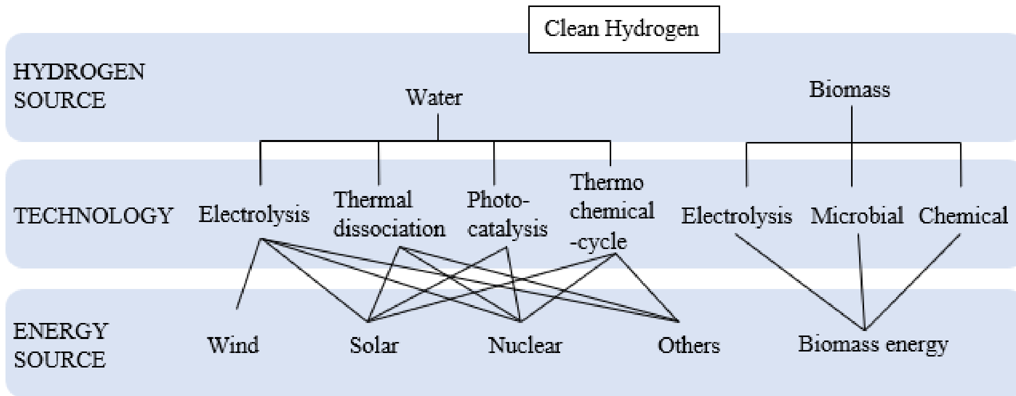


Figure 1. Hydrogen production methods from renewable energies (Wang et al., 2019).

Although it is true that from Figure 1, the only technology available on a commercial scale is water electrolysis (Takach et al., 2022), those that use biomass as a feedstock present a great potential and a sufficient TRL (Technology Readiness Levels) to assume that this type of process will be implemented soon. In the case, for example, of bio-methane with SMR (Steam Methane Reforming), the TRL is 9 (Rosa and Mazzotti, 2022). The advantages of using biomass as a hydrogen source over water include the following:

1. Biomass is cheaper than other dedicated feedstock and can even have a zero cost or, in some cases, generate an income through an input fee (Keogh et al., 2022).
2. The price estimation for hydrogen production from biomass is much more promising than the price using solar or wind energy (Wang et al., 2019).
3. Biomass can be stored and transported, making it a dispatchable energy source (Middelhoff et al., 2022).
4. Producing one kg of hydrogen requires 11 litres of water, which implies the need for a water surplus of 4.45 cubic hectometres per year, which is not the case for biomass (de la Fuente Rodríguez, 2023).
5. In the case of the use of residual biomass, an opportunity is provided for the management of waste that would otherwise end up in landfill is provided with the added benefit of revalorisation.

Besides analysing the different technologies considered for hydrogen production, the region's energy plans and strategies have also been considered. Here, the main document that marks the route towards the objectives set by the European Union is the Andalusia Energy Strategy 2030, approved in 2022 by the autonomous community's Governing Council. This strategy is proposed as a planning instrument, defining a strategic reference framework of twelve priority lines, among which the promotion of the use of renewable energies, the promotion of the bioeconomy and the circular economy associated with the energy sector stand out. Concerning the latter, it is worth highlighting the importance in Andalusia of the study and implementation of biomass-based energy technologies (Junta de Andalucía, 2022). According to the Secretary of Energy of the Andalusian Regional Government, Andalusia has a great potential for biomass production that can be analysed to meet the objectives of this work. Proof of this potential is the approval in 2018 of an Andalusian Circular Bioeconomy Strategy by the Regional Government (Agencia Andaluza de la Energía, 2020).

With the aim of serving as a basis for the future reconversion of hydrogen production sources, and to avoid the negative impact on the environment caused by using fossil fuels, this work has analysed the existing biomass in Western Andalusia as a source of green hydrogen production. As mentioned above, biomass plays an important role in the decarbonisation of the energy system. The use of this raw material for hydrogen production allows, unlike the renewable sources currently used, its storage and transport, which makes it more dispatchable.

2. Methodology

To select the biomass considered in this work, the following criteria have been considered. Firstly, the availability of the waste in the area of the study (provinces of Seville, Cadiz, and Huelva). The information was obtained from data provided by the Andalusian Energy Agency (Agencia Andaluza de la Energía, 2012). Once the availability in tonnes of each of the types of biomasses considered has been determined, a filter has been applied in which those types of biomasses for which less than 50 000 tonnes are produced have been discarded. This quantity has been chosen based on a previous study, bearing in mind that the maximum theoretical yield of hydrogen production from biomass (Akubo et al., 2019; García Martín et al., 2020; Hu et al., 2020; Sert et al., 2018), as a generic feedstock, is not very high (depending on the biomass considered, an average yield of hydrogen is 53 g/kg of treated (dried) biomass), so it is not viable to build a plant for a resource that is not widely available.

Secondly, it has been determined from the literature which biomasses have already been used for hydrogen production, the technology used and the conversion efficiency. This filter has reduced the type of biomass in the study from 23 different types down to 16. In this step of the study, the total amount of hydrogen that could be produced if all the waste biomass available in the study area was used for this purpose has been determined.

However, it must be considered that not all biomass is available for hydrogen production, as it can be used for other purposes, e.g., thermal or electrical generation, or animal feed among others. For this reason, a further step has been taken in the study, in which the different uses of the biomasses available have been evaluated.

Regarding the consideration of the use if the different types of residual biomass, insightful information has been found only for agricultural residues associated to olive industry (i.e., olive stone[1], olive pomace[2] and olive tree-pruning[3]). The different characteristics and properties of each residue are summarised in Table 1 (Vera et al., 2014). To depict where in the production process each of the wastes considered in the study is generated, a diagram of the olive oil industry is included in Figure 2. The wastes have been highlighted with a red square. The different uses found for these types of biomasses, as well as the percentage dedicated to each one, are summarised in Table 2 and Table 3 (Callejo López et al., 2015).

[1] Waste from both the olive mill after olive oil extraction and the extractor after orujo oil production.

[2] The olive pomace (also known as "orujillo") residue is generated as waste in the extractor after the production of orujo oil. It must be distinguished from the olive pomace generated in the mill, which is used to produce orujo oil.

[3] Residues generated after cleaning the olives just before processing.

Table 1. Properties of residues from the olive industry (Vera et al., 2014).

By-product	Olive tree-pruning	Olive pits	Pomace	Leaves and branches
Location	Olive grove	Olive mill	Olive mill	Olive mill
Production rate	2.5–3.0 t/ha	90–100 kg/t of olives	600–650 kg/t of olives	80–100 kg/t of olives
Ash content (%, ar[a])	3–5	0.5–2	2–5	8–10
Moisture (%, ar[a])	15–20	25–35	60–70	5–10
LHV (MJ kg^{-1})	16–18	17–19	16–18	10–13
Requirements	Cutting transport	Drying	Drying	None
Selling price (€ kg^{-1})	Free	0.15–0.20 (dry)	–	Free
Current application	Pellets	House boilers	Power plants (combustion)	Animal feed

[a] As received, the material in its original form (including ash and moisture).

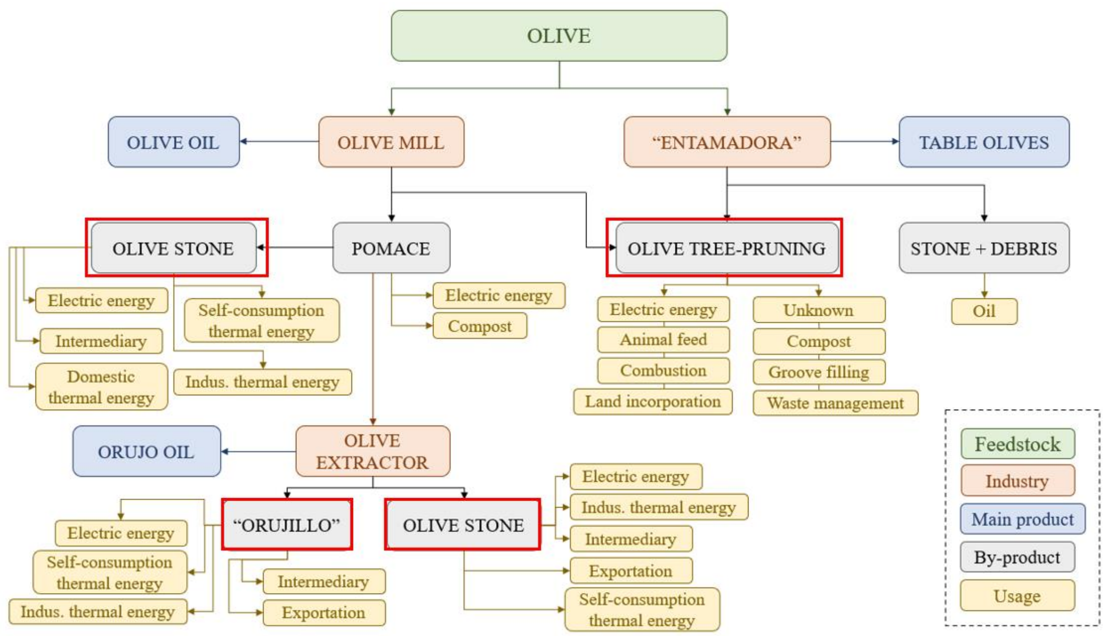


Figure 2. Olive oil industry.

Table 2. Uses of olive mill by-products (Callejo López et al., 2015).

OLIVE MILL	Olive tree-pruning (%)	Olive stone (%)
Direct incorporation in the soil	40.5	-
Power generation / Cogeneration	33.5	41.0
Animal feed	20.8	-
Waste management	2.90	-
Groove filling	0.600	-
Combustion	0.400	-
Unknown	1.30	-
Self-consumption thermal energy	-	18.9
Industrial thermal energy	-	11.2
Domestic thermal energy	-	4.30
Intermediary	-	24.6

Table 3. Uses of oil extractor by-products (Callejo López et al., 2015).

OLIVE EXTRACTOR	Olive stone (%)	"Orujillo" (%)
Power generation / Cogeneration	60.5	61.3
Industrial thermal energy	6.90	28.9
Export	13.8	3.70
Intermediary	18.8	6.10

Since a large part of the waste generated in the olive industry is used for energy purposes, in this work we have considered as available the quantities that refer to uses that do not compete with another sector. In the case of olive mill, those that are managed as waste (from which an economic benefit could even be obtained from their administration), burnt, handled through intermediaries, or those whose application is unknown. In the case of the olive extractors, it has been considered that the quantities of waste that are currently exported or managed by intermediaries could be used for hydrogen production.

3. Results

Once the actual available quantities of waste generated that can be used for hydrogen production have been determined, the energy potential for each of the wastes studies was represented in the area of the study with the aid of a Geographical Information System (GIS) software (ArcGIS Pro). From this representation, it can be seen where the highest energy potential is located with a view to transporting the most suitable raw materials to the chemical poles in the region. These are the chemical clusters of Huelva and Algeciras (Cadiz providence), located around *La Rábida* and *San Roque* refineries. Both clusters have been highlighted on the map with the symbol and name of the corresponding refineries. Figure 3 shows the three maps obtained for each of the wastes considered, as well as a diagram of the industrial process of the olive, to see more clearly at what point each of the wastes is obtained.

From Figure 3, it is noted that the energy density of the wastes considered is greater in the case of olive tree-pruning and in the surroundings of the Huelva chemical pole, and therefore, a priori, it would be more convenient to install the hydrogen production plant in this cluster. Furthermore, the amount of hydrogen, in tonnes, that could be obtained from the different wastes has been estimated, using the yields obtained in the literature for gasification and pyrolysis, as these are the most widely used technologies.

The total amount of hydrogen that could be obtained (using gasification) for olive tree-pruning (García Martín et al., 2020) and olive pomace (Sert et al., 2018), and pyrolysis for olive stone (Álvarez-Murillo et al., 2015) would be almost 4 400 tonnes. Since olive crops are seasonal, this study has also considered the monthly hydrogen production that would be according to the monthly amount of waste that would be generated. By this way, it is possible to know in which months of the year the greatest amount of energy is produced, which facilitates the coupling of biomass energy production with other types of generation involving, e.g., solar or wind energy. To calculate seasonality, oil production seasons from 2018 to 2021 have been considered. In this way, an average of the oil produced in each month was calculated, from which the amount of waste generated in thar month was obtained. The results achieved for the monthly tonnes of hydrogen that can be produced are shown in Figure 4, which also indicates the total quantities of each residue by province and the hydrogen yields per quantity of biomass according to the information available.

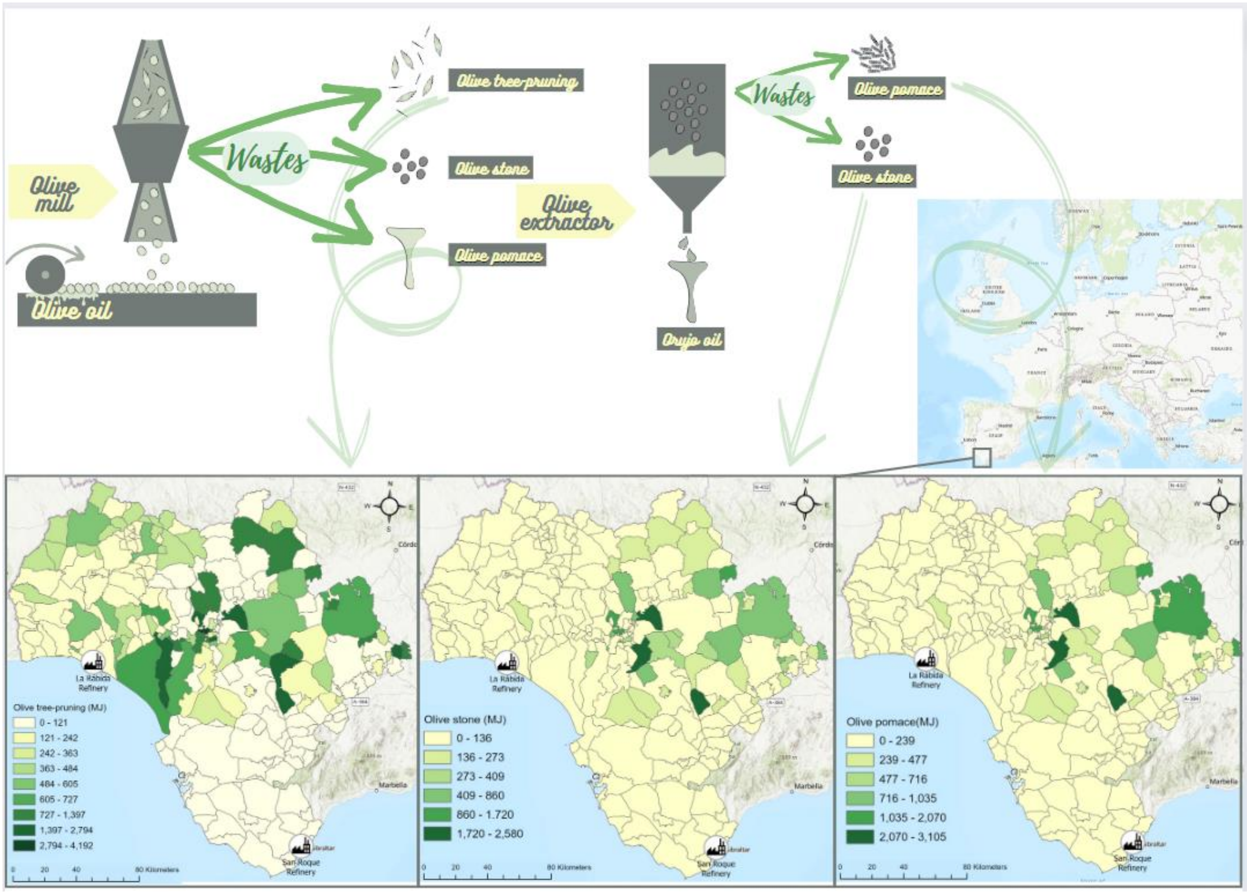
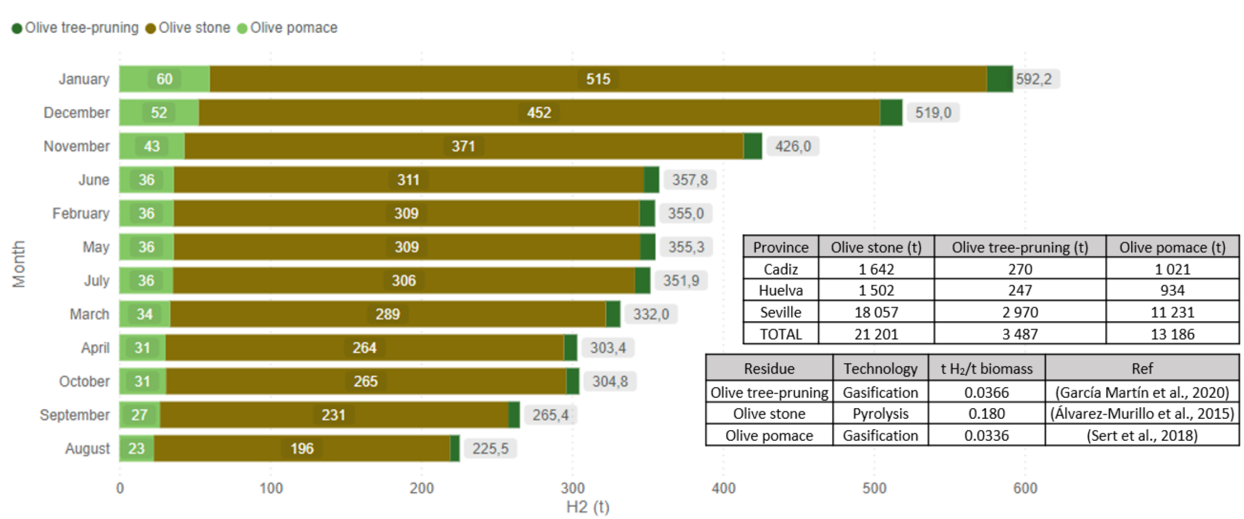


Figure 3. Potential energy resources from olive oil industry residues in western Andalusia.



Province	Olive stone (t)	Olive tree-pruning (t)	Olive pomace (t)
Cadiz	1 642	270	1 021
Huelva	1 502	247	934
Seville	18 057	2 970	11 231
TOTAL	21 201	3 487	13 186

Residue	Technology	t H_2/t biomass	Ref
Olive tree-pruning	Gasification	0.0366	(García Martín et al., 2020)
Olive stone	Pyrolysis	0.180	(Álvarez-Murillo et al., 2015)
Olive pomace	Gasification	0.0336	(Sert et al., 2018)

Figure 4. Potential hydrogen production using residues from olive oil industry in western Andalusia.

According to Figure 5, the months in which most hydrogen can be produced are January, December, and November. These are precisely the months with the least normal direct solar irradiation[4], so the

[4] Values consulted from the Photovoltaic GIS tool (create by the Joint Research Centre of the European Commission) for the *La Rábida* and *San Roque* refineries.

implementation of hydrogen production technologies from this type of biomass could guarantee the production of clean energy in the months when it is more difficult to apply other sources of renewable energy (i.e., solar energy). Another important point in Figure 5 is that, despite olive tree pruning being the residue with the highest energy density in the area, the highest amount of hydrogen is obtained from olive stones. Thus, it would be advisable to carry out a more in-depth study to assess whether it would be more convenient to use olive tree-pruning for hydrogen production.

4. Discussion

From the results obtained, an important and real potential to produce green hydrogen from existing waste biomass is observed in the area proposed for the study. Specifically, it has been obtained that, from the three agricultural residues studied, almost 4 400 tonnes of hydrogen could be obtained, to which could be added the hydrogen produced by the rest of the wastes that have not been considered due to a lack of knowledge of their current use. Furthermore, it has been verified that, by representing the available quantity of each waste using GIS software, a map is obtained that is quite similar to that of the energy density. This information suggests that the most interesting location for the implementation of the green hydrogen production plant would be close to one of the chemical clusters proposed (i.e., the Huelva chemical cluster).

Another key point of the study is the analysis of the seasonality of biomass waste. From this analysis, it has been possible to verify that the seasonality of the residue studied fits quite well with the availability of solar energy, as the months of greatest production of olive biomass residue coincide with the months of lowest direct normal irradiance.

5. Conclusions and Future Work

As a result, the study shows that it is possible to verify and evaluate the energy potential of western Andalusia in terms of biomass using public information. In addition, a methodology has been proposed such that, having data on the use of other types of waste available in the region, their contributions in terms of green hydrogen generation could be included.

Additionally, the study conducted has served as a basis for a broader analysis of the possible potential for hydrogen generation in the study region, as well as for comparison with the possible demand for this vector that can be found in the chemical clusters located in the area of the study.

It is also proposed to continue with the development of this study to consider the possible routes for transporting the residues from the olive industry to the Huelva chemical cluster. In this way, the economic costs and associated CO_2 eq. emissions that would be generated by the proposed value chain could be also considered.

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