Characterisation of residues flows (MSW, forestry, agricultural) at Iberian level

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Abstract

The growing concern about climate change associated with the health hazard of greenhouse gas (GHG) emissions in urban areas has triggered research and development of firt-generation biofuels. However, recent studies have shown some of the limitations of this type of biofuels, which has led to research into second generation biofuels, which include advanced biofuels, produced from forestry, agricultural, agro-industrial and organic residues, rather than from oil-based materials. Due to the different chemical characteristics of the raw materials, the existing technologies are very diverse. Considered a potential niche market, it became important to carry out the analysis of the potential of this market in the Iberian Peninsula due to the strong presence of Galp in Portugal and Spain, identifying the potential of the main existing technologies and their potential for evolution as well as the expected market growth, and the potential for conversion into advanced biofuels. Here, the main conclusions about the advanced biofuels market through the study of the most promising technologies are made, the projection of the consumption behaviour of fossil fuels, electricity and biofuels in the various transport sectors, the survey of forest, agricultural, agro-industrial and organic residues and finally, the production costs associated with the various technologies and raw materials.

Key-words: Residual biomass, Advanced biofuels, RED II, Residual biomass processing technologies, Availability of forest, agricultural, agro-industrial and organic residues, Market potential, Conversion potential, Production costs

1. Introduction

First-generation biofuels such as FAME biodiesel is produced from oil-based matter - virgin oils such as soybean and rapeseed. These raw materials have downsides, since they are part of the human and animal food chain combined with the use of agricultural land for the production of these crops, further intensify the problem of food fuel dependence. Also, certain raw materials do not allow GHG emissions reduction, especially in the production of first-generation bioethanol. The need to reduce GHG emissions has allowed the growth of other sustainable alternatives, such as electric mobility and incorporation of hydrogen in the transport sector, but also possible substitutes for first-generation biofuels, such as advanced biofuels.

The high importance of this type of biofuels resulted in the introduction of targets by 2030 by the European Union in the *Renewable Energy Directive II*, referred to as RED II. This directive divides biofuel feedstocks into two parts A and B, where part A concerns the feedstock of advanced biofuels: forestry, agricultural, agro-industrial, and non-hazardous organic waste. Part B concerns oleaginous residues: used cooking oil (UCO) and animal fat. UCO and animal fat are used for the production of FAME as well as HEFA (Hydrotreated Esters and Fatty Acids) used in aviation, with a maximum incorporation limit of around 1,7% in the transport sector [27].

The reason why the REDII set a maximum limit for this type of biofuel is due to the intense competition for Part B raw materials between biofuel producers and the chemical industry. More specifically, detergent producers who used this waste material as a raw material for saponification, and given the growing demand from the biofuel industry, started to buy cheap virgin oils, such as soybean and rapeseed. Thus, the problem associated with growing oil crops on agricultural land remains, as does deforestation for their production. On the other hand, for the advanced biofuels, whose raw materials are in part A, favourable incorporation targets of 0,2%, 1,0% and 3,5% of final energy consumption in 2022, 2025 and 2030, respectively, have been established. These targets may be met by any sector, but the final energy consumption concerns the road and rail sector, since it is in these sectors that biofuels have a greater presence and the incorporation infrastructures are already well established. Specifically, for the maritime and aviation sector there is the incentive of a multiplier of 1,2 the energy content for biofuels incorporated in these sectors [1] [6] [19] [27].

2. Advanced Biofuels

Technologies used to produce advanced biofuels can be biochemical, chemical or thermochemical. Unlike first-generation biofuel technologies, the great advantage of these technologies is the diversity of biofuels produced, but also the possibility of producing *drop in* biofuels, i.e., that have the same characteristics as fossil fuels, without the need for engine modifications. The gasification process followed by Fischer-Tropsch (FT) synthesis is an example. The most promising ones are, according to the studies Low Carbon Energy Observatory - Technology Development Report of the year 2018 [23] and that of 2020 [24]:

- Enzymatic fermentation
- Second-generation alcohol catalysis (ETD, ATJ, MTG)
- Gasification with Fischer-Tropsch
- Gasification with catalytic synthesis
- Pyrolysis

Although enzymatic fermentation technology is the most promising and closest to commercialisation, the European market, unlike that of North and South America, is dominated by diesel. Hence, the processes that allow diesel production seem to be more relevant, but the electrification of the light road sector greatly reduces the consumption of gasoline and, therefore, bioethanol.

2.1. Biochemical and chemical technologies

The main biochemical technology is enzymatic fermentation, which produces alcohols such as cellulosic ethanol and butanol. It consists of a first pre-treatment step, followed by the hydrolysis step, in which cellulose and hemicellulose are converted into simpler sugars such as glucose, so that the enzymatic fermentation is the most efficient at converting the sugars into ethanol.

This biochemical process presents some barriers associated with the pre-treatment step, given the presence of lignin, which hinders the attack on the cellulose and hemicellulose of the lignocellulosic residues and also the high cost of enzymes. There are some units that have overcome this barrier through their own production of enzymes, as well as subsequent regeneration and reuse of these.

The chemical technology of producing fuels through alcohols through catalytic synthesis is a commercial process and well developed in the industry. It consists of the conversion of alcohols such as ethanol, methanol or butanol into fuels such as diesel, petrol and jet. The steps are well established chemical reactions and depending on the fuel, the chemical process is chosen. The chemical process with the greatest economic interest is the production of jet, designated as ATJ - *Alcohol to Jet* - but it is still uneconomical and with a TRL of 5-6.

2.2. Thermochemical technologies

Thermochemical technologies are well-established processes with raw materials such as coal.

2.2.1 Gasification

The gasification technology consists of reacting biomass, in this case with pure oxygen or air, whose reaction product is synthesis gas or *syngas* composed of CO and H_2. In certain cases, the sensitivity of the gasifiers to the composition and size of the raw material requires a pre-treatment, which entails even more costs and constitutes a relevant barrier in the process. Next, the *syngas*, which must be pre-treated, can be converted into fuel through Fischer Tropsch synthesis or for hydrogen production only, through the *water-gas shift* reaction, which is often used prior to biofuel production to increase the hydrogen content.

Fischer- Tropsch or BtL

The *syngas* is converted into diesel, gasoline and biojet considered *drop in*. This process presents some barriers, such as the rapid deactivation of catalysts that imply that there is more research in this area, as well as the need for economies of scale so that it becomes profitable. Despite these barriers, it is considered very promising according to several studies like the Low Carbon Observatory reports [23][24].

Catalytic synthesis

This technology allows the conversion of *syngas* into ethanol or cellulosic methanol and through methanol, the production of dimethyl ether (DME). The main route used is the production of methanol and presents a very high potential mainly through organic residues.

Pyrolysis

The pyrolysis process, depending on the operating conditions, can produce pyrolysis oil - also known as bio oil -, gas and tar. As the objective is the production of liquid fuels, the bio oil component is the desired one and to maximise its production in relation to the other possible products, the fast pyrolysis technology is applied. Mostly, bio oil is produced in a unit near a traditional refinery and then co-processed with crude oil. Despite the high potential, bio-oil has certain characteristics that make co-processing very difficult, such as its high viscosity and corrosion, which is a problem since the vast majority of the refinery pipework is made of carbon steel, not suitable for corrosive compounds. In addition, the high oxygen and water content also represents a barrier. Thus, pre-treatment of this compound is costly, the main reason why it is no longer present in the industry, even with a TRL of 6-9.

Hydrothermal Liquefaction

This technology allows the production of bio-oil by processing wet feedstock, not requering the drying step. Despite this innovative technology, it is still at a very early stage, with a TRL of 5-6. Table 1 presents the summary of the technologies in terms of TRL.

2.3. Conversion potential

The study of the potential of conversion of residues requires the evaluation of the admissibility of certain raw materials, according to technology. A portuguese project CONVERTE [20], developed by LNEG and concluded in 2018, studied this parameter along with other subjects. This study studied the admissibility of certain samples, such as as selectively collected bioresidues or olive pits for the main advanced biofuels production technologies, before and after drying step. The main conclusions are that the technology with the highest number of admissible residues is enzymatic fermentation, because it does not depend on the water content, unlike gasification, pyrolysis or hydrothermal liquefaction. On the other hand, after drying, residues such as extracted olive pomace and green residues can be used as feedstock for gasification (¡30%), the same is not true for pyrolysis because the percentage of moisture must be even lower (¡20%). As the pyrolysis technology is the one that presents the most rigid limit in terms of water content, it is the one that presents the least potential for the admissibility of various raw materials.

3. Market potential for advanced biofuels

To estimate the market potential for advanced biofuels it was necessary to study fuel consumption in the road and rail sector, in order to estimate the necessary consumption of advanced biofuels. The REDII presents several rules for calculating these minimum quotas, designating, for example, that the electricity consumed in the road and rail sector has a multiplier of 4 and 1,5, respectively. Thus, the calculation of the denominator consisted in the sum of the estimates of consumption of petrol, diesel, electricity, LPG, biofuels and natural gas according to the suggested multiplicative factors. Then, for the calculation of advanced biofuels, the numerator, the minimum share for each year required in REDII was applied. The results obtained are in the tables 2 and 3 according to the three scenarios established, where scenario A is the most ambitious and C is the least ambitious in terms of decarbonisation. To meet the minimum shares set in RED II, it can be seen that in 2030 the consumption of advanced biofuels part A is lower than in 2022 or 2025 whose minimum share is lower and this is due to the estimation that fuel consumption in the transport sector will progressively decrease. Although the calculation of the minimum quotas depends mainly on the consumption of the road and rail sectors, the aviation and maritime sectors have also been studied. According to a study by IRENA [17], the aviation sector will be the main consumer of advanced from 2030, as the electrification of this type of engines is still very difficult because of the need that requires fuels with high energy content. Due to the COVID-19 pandemic, the future of aviation is one of the biggest unknowns. Not only because of the present fear and discouragement by governments to make tourism outside the countries but also the decrease of work trips. The three scenarios contemplate the possibility of a decrease or increase in jet fuel consumption. Despite the high potential of this market, it is fundamental to intensify the legislation favourable to this type of biofuels, since it will be preponderant for this market to develop as well as possible. In terms of potential, the Iberian Peninsula presents an enormous potential for the development of this market not only because there is favourable legislation, but also because there is a growing concern with the environment and climate change which is reflected in the accelerated growth of the electric and hybrid market. The development of initiatives to educate the population to know what advanced biofuels are and the importance of their consumption will be fundamental as an incentive to consumption.

4. Methodology

To estimate the availability of the residues, present in part A of REDII, different methodologies were used, depending on the country and type of residue. The estimates of forestry, agricultural, agro-industrial and bioresidues for Portugal and Spain are presented in the table 4.

When analysing the table 4, the generation of

Table 1: TRL of technological routes for the valorization of residual biomass

Technology	TRL
Enzymatic fermentation	7 - 9
Second-generation alcohol catalysis	5
Gasification with Fischer-Tropsch	5 - 6
Gasification with syngas fermentation	5 - 7
Gasification with catalytic synthesis	8
Pyrolysis	5 - 6
Hydrothermal Liquefaction	4
Transesterification of residual oils/fats	9
Hydroprocessing of residual oils/fats	9

Table 2: Potential for the advanced market in Portugal between 2022 and 2030 in pentajoules (PJ)

	Portugal								
Scenarios	**A**			**B**			**C**		
Year	**2022**	**2025**	**2030**	**2022**	**2025**	**2030**	**2022**	**2025**	**2030**
Denominator	206	187	181	207	190	187	217	214	233
Numerator	**0,2**	**0,9**	**3,2**	**0,2**	**0,9**	**3,3**	**0,2**	**1,1**	**4,1**
Total Biofuels	**38**	**37**	**35**	**38**	**37**	**35**	**38**	**37**	**35**

Table 3: Potential for the advanced market in Spain between 2022 and 2030 (PJ)

	Spain								
Scenarios	**A**			**B**			**C**		
Ano	**2022**	**2025**	**2030**	**2022**	**2025**	**2030**	**2022**	**2025**	**2030**
Denominator	1 053	943	787	984	872	715	1 036	999	970
Numerator	**1,1**	**4,7**	**13,8**	**1,1**	**4,8**	**13,7**	**1,0**	**5,0**	**17,0**
Total Biofuels	**59**	**57**	**54**	**59**	**57**	**54**	**59**	**57**	**54**

Table 4: Residues in Portugal and Spain (kton/year)

Residues	Forestry	Agricultural	Agro-industrial	Bioresidues (2020-2035)	Total
kton/year					
Portugal	2 300 a 2 500	2 300 a 2 700	670	1 500 a 2 200	6 770 a 8 070
Spain	5 600 a 7 300	18 400 a 31 400	16 330	5 500 a 6 200	48 030 a 61 230
Total	7 900 a 9 800	22 900 a 34 100	17 000	7 000 a 8 400	54 800 a 69 300
	ton/km2 of area (forest or agricultural). year				
Portugal	71 a 78	71 a 84	2*		
Spain	31 a 40	613 a 1046			
ton/per capita.ano					
Portugal	0,24 a 0,26	0,24 a 0,28	2*	0,15 a 0,22	2*
Spain	0,12 a 0,75	0,40 a 0,68		0,12 a 0,13	

forestry and agricultural residues in Portugal is almost the same *per capita* unlike Spain that is estimated to generate more agricultural residues *per capita*. On the other hand, per kilometre of area, in Portugal is quite similar between these residues, however in Spain the ratio is much lower than in Portugal and the difference between forestry and agricultural residues is very disparate, proving the potential of agricultural residues in Spain. The bioresidues are in similar ranges, being higher *per capita* in Portugal [15].

4.1. Forestry residues

4.1.1 Portugal

In this study, the estimation of this type of residue in Portugal consisted of the information present in the "National Plan for the Promotion of Biorefineries" (PNPB) [9] and the studies "Charaterisation of forestry biomass supply chains in Portugal: Part I Analysis of flows of installed capacity for processing" by INESTEC [16], "Report of the Biomass Working Group" by the Fisheries Commission [7], as well as in the data from the 6th National Forestry Inventory (IFN6) [14]. The reason was due to the data reported in the National Plan for the Promotion of Biorefineries being from the year 2017 and does not account for the fires of 2017 and 2018 in Portugal, which mainly affected maritime pine, and through this association of methodologies it is possible to estimate the most updated value possible. As such, the INESTEC [16] methodology, which considers maritime pine and eucalyptus, together with the IFN6 [14] data, allows to estimate the amounts of residues of this species after the fires, given that IFN6 was updated at the end of 2019. As for the remaining species reported in the PNPB [9], they are estimated to be the same. Given the use of forestry residues in biomass and cogeneration plants, it was necessary to consider this consumption, so the residues consumption per MW was estimated and then, the consumption per forestry residues plant. The values obtained are presented in the table 4 and are in the range of 2 300 and 2 500 kton/year, values in agreement with the values suggested by J.E Carrasco et al. [21] and [10], which suggest that there are in Portugal about 2 230 kton/year and 2 000 kton/year, respectively. In summary, the regions with the highest forestry residues potential are the Alentejo, given that there is no plant in this region followed by the Centre and North.

4.1.2 Spain

The estimation of forestry residues in Spain is through a different methodology than the one applied for Portugal. It is based on the article Fernández et al. [26], which estimates the availability of forestry residues in Spanish provinces. To estimate the consumption of biomass and forestry residues from biomass and cogeneration plants was determined in the same way as for Portugal, through the installed power and a fixed consumption value which is about 10.76 kton of residues/MW. After accounting for forestry residues consumption, the availability of this residues in Spain is around 7 300 kton/year since the potential is 12 975 kton/year. The regions with the highest estimate of forestry residues are Castilla-León, followed by Castilla-La Mancha, Aragón and Extremadura. Specifically, the provinces with the highest potential are Cárceres in Extremadura and Huesca in Aragon. The estimate made is in accordance with the article [26] which indicates that there are between 10 550 and 4 000 kton/year. On the other hand, a forestry strategy study in Spain [8] indicates that there are about 6 000 kton/year of forestry residues available for energy use. For both Portugal and Spain, the exploitation of forestry residues for fuel allows the development of rural areas through the creation of new jobs.

4.2. Agricultural residues

The agriculture sector generates high and varied amounts of residues. To estimate the amount of agricultural residues, the methodology of the paper "Biomass resources and costs: Assessment in different EU countries" [21], through residues-to-product ratios present in the bibliography [22] [2] [13]. As the data for the year 2019 was not available in the platform of the Portuguese INE, the values used were from the FAO platform [11] and for Spain, the values used were on the website of the *Ministerio de Agricultura, Pesca y Alimentación* [12]. After a first estimate of the agricultural residues generated, sustainability factors were applied in relation to some products such as rice and barley, to consider the need to keep part of the residues in the soil for moisture and soil fertility issues [22]. For the agro-industrial residues, product residue ratios were also applied for the calculation of brewery, rice as well as olive pit and extracted olive pomace.

4.2.1 Portugal

The initial estimate of agricultural residues in Portugal was 2 736 kton/year and with the sustainability factor, 2 267 kton/year as presented in the table. The region with the highest potential, with the generation of 1 200 kton/year, is Alentejo, followed by Centre, North, AML and finally, Algarve. Despite this estimate, much of the agricultural residues is already recovered in the companies themselves, mostly for compost, but the degree of recovery is difficult to predict.

4.2.2 Spain

The agriculture in Spain is one of the main business sectors in the country whose production volume is higher and with greater diversity. The estimate is between 20,600 and 31,400 kton/year, according to the sustainable removal or not of agricultural residues. The crops that generate the greatest number of residues are barley and olive groves. In turn, Andalusia is the region with the highest generation of residues with 5 118 651 kton/year, followed by Castilla Leon with 3 722 996 kton/year, Castilla-La Mancha with 2 240 217 kton/year, Extremadura with 1 698 001 kton/year and finally, Aragon with 1 635 251 kton/year. Assuming that a supply chain is established between Spain and Portugal, the regions of greatest interest, for reasons of distance, are Andalusia and Extremadura.

4.3. Agro-industrial residues

The agro-industrial sector generates a diversity of residues, so it was decided to study brewery dreche and rice husk as suggested in the study carried out between LNEG and FCT entitled “The national potential for the production of biofuels from agro-industrial residues” [5]. The agro-industrial residues in Portugal and Spain are quite different values, resulted from a Spanish brewing and olive oil industry much higher than the Portuguese, with 671 kton/year and 16 380 kton/year, respectively. The big difference is seen in the production of olive groves and beer, which in turn contributes to a much higher estimate. As well as the agricultural residues, the agro-industrial residues are already valued energetically and with a greater expression, mainly in olive groves where olive stones and extracted olive pomace are burnt. For these reasons, the extracted olive pomace values may not be so realistic and according to the study of LNEG and FCT [5], the values are much lower for Portugal, extending this conclusion to Spain.

4.4. Municipal Solid Waste (MSW)

This type of residue is regulated and managed differently than the others, due to public health and other issues. Thus, it has a much stricter regulation and policy, following the indications and targets imposed by the EU. Additionally, it depends on several factors, which the other wastes do not depend on such as economic and social factors. In turn, it depends on the population and measures applied, as it implies that the estimation needed is different from the one performed for forestry or agricultural residues. The estimation method was different because it is necessary to consider the annual variation of MSW, unlike forestry and agricultural residues which tend to be stable and when they are not the reason is usually due to natural disasters or fires, impossible to predict. The implementation of separate collection in the EU of bioresidues by the end of 2023 aims to increase the efficiency of waste management but also of organic recovery. The estimation of bioresidues was carried out by extrapolating the bioresidues uptake until 2035, establishing two scenarios, one of growth and one of general decrease. Table 5 presents the summary of the results obtained for the Iberian Peninsula.

4.4.1 Portugal

In Portugal, the recovery capacities of the current and projected mechanical and biological treatment units (TMBs) were analysed according to the Strategic Plan for Solid Municipal Waste + (PERSU+) [3] for the period 2020 to 2025. In relation to the projected scenarios, the first scenario allowed estimating that between 2020 and 2035 the generation of bioresidues increases from 1.9 to 2.2 million bioresidues. On the other hand, the second scenario estimates a decrease, for the same period, from 1.9 to 1.5 million tonnes per year. Next, when analysing the organic recovery capacity, after the implementation of selective collection, many of the municipal waste management systems (SGRU) will not have the capacity to fully recover the bioresidues. The main units belong to the management systems of urban centres such as Lipor, VALORSUL and AMARSUL. In summary, the greatest potential to valorise bioresidues from selective collection is in urban centres such as Lisbon and Porto, verifying that the regions with the greatest potential are the Centre, North and AML, noting that there are certain SGRUs that process waste from different regions, hence it is important to consider both the regions and each SGRU. As such, there is an opportunity for advanced producers such as GALP to valorise the bioresidues that the SGRUs cannot.

4.4.2 Spain

Due to the system of autonomous communities in Spain, the differences are more marked. While in Portugal there is a constant practice of measures between regions, in Spain the difference is very marked. For example, in Barcelona, the measure of selective collection of bioresidues has been applied since the 1990s. The regions with the greatest potential are Andalusia, Catalonia, Comunidad Valenciana and Madrid. On the one hand, landfilling is predominant in the regions of Murcia, Andalusia and Aragon. On the other hand, the communities with the use of incinerators such

Table 5: Projection of bioresidues generation according to various scenarios in Portugal and Spain between 2020 and 2035 (kton/year)

Year	Portugal		Spain
	A	B	A
2020	5 040	5 110	61 430
2020	5 470	4 840	5 914
2025	5 900	4 580	5 640
2035	6 330	4 318	5 449

as Cantabria, Catalonia, Galicia, Madrid, and the Autonomous Community of Navarra show low percentages of landfilling. As no information was found on the capacity of the TMBs in Spain, it was not possible to conclude on which regions have the greatest potential due to their lack of organic recovery capacity for bioresidues. However, through the 2018 MSW statistics in Spain, it was possible that only Andalusia and Catalonia have higher organic recovery capacities, but well below the generation of bioresidues of each of the regions.

5. Production Costs

n addition to the barriers of the advanced in relation to the lack of clear and stable policies in the EU, another important barrier is the technological one, which is associated with the high cost of production of this type of biofuels. The study of production costs is fundamental to understand which are the main factors for the production cost and then, predict which is the potential for production cost reduction, being one of the main factors for the conclusion of which technologies to apply. For the analysis of the production costs of the technologies, two studies were analysed: "Building up the future- cost of biofuel" [25] developed by SGAB - *Sub Group on Advanced Biofuels* - group created by the European Commission 2017, and "Advanced Biofuels: Potential for Reduction" prepared by IEA Bioenergy [4]. Data regarding production costs were analysed, as well as the cost reduction potential associated with each of the technologies.

The decrease in production costs is estimated to result substantially from two parameters: the reduction of raw material costs, through the establishment of more efficient supply chains, and the reduction of operating costs, through a deeper knowledge of technologies at large scale, as well as the optimization of the use of co-products, which is estimated, like petrochemical refineries, to represent about 50% of the total profits of the sector. The units in the two studies, as they deal with biofuels with variable calorific values, defined the investment costs in €/kW of biofuel production capacity and €/MWh for production costs. In this study, the output of each unit was considered to be 100 MW of power production, operating 8,000 hours per year, guaranteeing the production of 800 GWh of energy as a final product, which is equivalent to 137 million litres of bioethanol. In both reports, the analysis of technologies is rather limited as it analyses enzymatic fermentation for bioethanol production, gasification with Fischer Tropsch synthesis, gasification with catalytic biomethanol production and pyrolysis with bio-oil production.

The two scenarios presented in the SGAB [25] study are called *low* and *high*, differing exactly because one presents higher costs than the other. However, as the [4] study reviewed the SGAB study, it estimated other scenarios for the production of FT fuels and biomethanol by catalytic route. The main conclusions are presented in the table 6.

The technologies with the highest reduction potential are gasification followed by catalytic synthesis through forest and agricultural residues and MSW. This is followed by gasification technology and synthesis of FT through MSW. Biofuels of thermochemical origin present a higher potential since their costs, in energy terms, are lower and as such, the input required is lower to obtain the same energy output.

6. Technology Conversion

After projecting the necessary number of advanced biofuels to incorporate to meet the REDII minimum quotas and estimating the quantities of waste in the Iberian Peninsula, the conversion potential was estimated, according to the energy and mass conversion values of the IRENA study, "Innovation Outlook Advanced Liquid Biofuels" [18] of 2016, which considers the technologies of enzymatic fermentation, gasification followed by catalytic methanol production, for gasoline production, followed by FT synthesis, followed by syngas fermentation and finally, pyrolysis.

The agricultural and forestry residue values for this estimate are the lower limit determined. For calculation purposes, it was considered that the units would be the first commercial units. Additionally, it was considered that, according to the CONVERTE project, agricultural waste such as rice husk and brewery dreche would be used for bioethanol production through enzymatic fermentation and that extracted olive pomace and olive stones would be used for gasification. Forest residues can be applied for any technology due to

Table 6: Production costs before and after a possible cost reduction of the main technologies

€/MWH	**Production Costs**	**After a possible reduction**
Etanol	85 a 158	76 a 122
Biocombustíveis FT	86 a 144	40 a 125
Biometanol	48 a 144	36 a 102
Pirólise	79 a 139	75 a 132

low moisture and high PCI. Thus, for the total the technology that allowed the maximum conversion number of these residues was chosen, highlighting pyrolysis and gasification followed by FT synthesis, the last one being chosen since its potential for production cost reduction and technological advance is estimated to be higher than that of pyrolysis. By analysing the tables 2 and 3 referring to the amount of advanced biofuels needed to be incorporated in 2022, 2025 and 2030 to meet the minimum quotas implemented in REDII, together with the table 7 it is possible to conclude that both countries do not have the capacity to fully produce the necessary amount. This implies that it is necessary to import this type of biofuels, which decreases the estimated GHG emission reduction.

7. Conclusion

The aim of this work was to estimate the potential for Galp Energia to implement advanced biofuel production technologies through residues in the Iberian Peninsula. Mandatory targets for the incorporation of these biofuels are the main driver for this study. As such, the implementation of these biofuels in final energy consumption implies the importation or an investment in production units in the Iberian Peninsula, as there is no production of advanced biofuels.

The technologies with the greatest potential are ethanol production by enzymatic fermentation, catalysis of 2G alcohols and gasification with FT synthesis, according to the type of biofuel they produce, number of existing and planned units. In terms of production cost reduction, it is expected that in 5 to 10 years, with a lower production cost per MWh of product for gasification technology with FT synthesis.

The study of the quantity and the conversion potential of the residues allowed the conclusion that the most promising technology, due to the ability to process a large part of the raw materials, is enzymatic fermentation and not gasification, despite presenting a reduction of production cost up to 40 €/MWh (in the case of FT synthesis) *versus* 76 €/MWh, relative to enzymatic fermentation. The decision of which technologies are the most promising depends on several factors and there is no single answer. This is due to several factors, e.g., the higher interest in jet and diesel in the European market, which tends to imply a higher potential of 2G alcohols gasification and enzymatic catalysis technologies. Depending on the objective, if it is to ensure a constant residues stream, the enzymatic fermentation technology is preferable, despite the high potential of the other technologies, except pyrolysis which has very little admissibility in terms of raw materials.

In terms of residues, the largest residues generation comes from the agriculture sector, where Portugal is between 2 500 and 2 700 kton/year and Spain between 20 600 and 31 400 kton/year. In terms of agro-industrial residues, the estimate is more disparate, i.e., Spain has a potential of 16 380 kton/year, mainly due to its high production capacity for beer, which translates into a high quantity of brewery dreche, whereas Portugal has a potential of 671 kton/year. Then, the forestry activity guarantees a potential where Portugal between 2,300 and 2,500 kton/year and Spain between 5,600 and 7,300 kton/year. Finally, the generation of bioresidues is estimated at between 7 000 and 8 400 kton/year on the Iberian Peninsula, with Portugal contributing between 1 500 and 2 200 kton/year and Spain between 5 500 and 6 200 kton/year.

Some Spanish regions close to Portugal, such as Andalusia and Extremadura, have very high residues estimates and the implementation of a supply chain between them is very favourable. Given the already existing valorisation of part of the forestry and agricultural residues for other purposes, bioresidues should be the one with the greatest potential in the Iberian Peninsula. Despite the existing barriers, the great fragmentation due to the various different types of technologies and the aggravating factor that there is no single energy market in the EU, can be overcome through more stable, clear and favourable policies. Based on several industry studies, it is believed that advanced biofuels will be important between 2020 to 2030 for the decarbonisation of the road sector, becoming complementary to electric mobility. From 2030 onwards, it is estimated that type of advanced will be decisive for the decarbonisation of the aviation sector, due to the high energy density required by engines.

Finally, the residues estimate for both countries is not sufficient to meet the minimum quotas implemented by the REDIIs. For the year 2022, whose

Table 7: Projection of advanced biofuels production in Portugal and Spain in 2022, 2025 and 2030

Fuels (PJ)				
Year		**2022**	**2025**	**2030**
Total Portugal	**Scenario**	0,05	0,05	0,06
	Scenario B	0,05	0,05	0,05
Total Spain		0,33	0,33	0,32

minimum quota is the lowest, Portugal if it had an advanced unit, which most likely it will not have, because none is planned, would only be able to produce, 0,05 PJ *versus* 0,2, imposed by the minimum quota. But even so, it is important to invest in their domestic production in order to maximise their GHG emission reduction potential. Furthermore, a large part of these technologies require treatments through H_2 and as such will benefit from Portuguese and Spanish projects for the production of green hydrogen, as in other areas such as methanol production through CO_2. The solution lies in the combination of several different projects to achieve carbon sustainability.

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