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Deliverable 1.2

Title: **Available agricultural/forest residues and process residues of common interest for EU and Brazil**	
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1. Introduction

Biomass is the largest renewable energy source in Europe with respect to current use and will be the major contributor into the future, according to future projections. Based on the evaluation of the NREAPs data, the ECN/EEA report (Beurskens and Hekkenberg, 2011) indicates, among others, that solid (lignocellulosic) biomass accounts for 78% renewable heating and cooling output. Unexploited biomass quantities could play a significant role in increasing the penetration of biomass in the European, national and regional energy balance supporting member states to meet their 2020 and beyond energy targets.

There are a number of studies on biomass resources on global and European level published over the last 20 years and numerous projects carried out in the EU (i.e., EUBIONET, BEE, Biomass futures, S2BIOM, etc), which quantified the actual and potential biomass availability in/and outside Europe. In 2013, the total biomass harvested in the EU and used from the EU agricultural and forestry sectors was estimated by JRC at 805 Mt dry matter (578 Mt from agriculture, 227 Mt from forestry), and another 119 Mt were grazed in pastures (Camia A et.al, 2018). In this study, feed and food uses was the most important category adding up to almost 62% of the biomass, while bioenergy and bio-materials were quite balanced accounting for circa 19% of the total biomass in the EU-28. However, it is important to note that biogas and bioelectricity have not been considered while bioenergy and biomaterials may have been underestimated due to large data gaps.

Among the EU biomass resources, agricultural residues are the most abundant and with the highest availability. A review made by Esteban and Carrasco in 2011, over 11 EU countries representing 77% of the total EU territory, estimates the potential of agricultural residues of 364,50 Tg y-1, of which 56% are available to be used under sustainable conditions, which is equivalent to almost 4% of the present EU gross inland energy consumption. Recently, it was estimated that agricultural residues could potentially supply 16% on the road transport fuel needed in 2030, generating more than 60% GHG savings and up to 300,000 jobs, mostly in the rural areas (Malins et.al, 2014).

This work is carried out in the frame of the BECOOL 'Brazil-EU Cooperation for Development of Advanced Lignocellulosic Biofuels' project. The main objective of the BECOOL (EU) and the counter project BioVALUE (Brazil) is to strengthen EU-Brazil cooperation on advanced lignocellulosic biofuels. Information alignment, knowledge synchronization, and synergistic activities on lignocellulosic biomass production logistics and conversion technologies are key targets of both projects and will bring mutual benefits. Both projects are structured in 3 main pillars covering in a balanced way the whole range of activities of the biofuels value chain (biomass production, logistics, conversion and exploitation).

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2. Objectives and Approach

This deliverable D1.2 refers to the first work-package WP1 'Biomass production and feedstock diversification for advanced biofuels' and more specifically to 'Task 1.1. Literature review on biomass assessments', which aims at the comprehensive assessment of the available agricultural, forest and industrial lignocellulosic residues of potential interest for advanced biofuels in EU and Brazil.

The approach that was followed was two-fold:

a. Literature review biomass availability in Europe
b. Use of the BIORAISE model
c. Literature review for biomass availability in Brazil

2.1 Literature review biomass availability in Europe

A search in past projects, studies and relevant literature reviews was carried out in order to identify assessment tools and project findings that could be used in this project in order to identify biomass feedstocks of common interest with Brazil. The required information covered Southern EU regions, so as to allow synergies with the Brazilian partners. The literature review was focused on the work carried out in the projects listed in D1.1 as well as to other papers so far published on this issue.

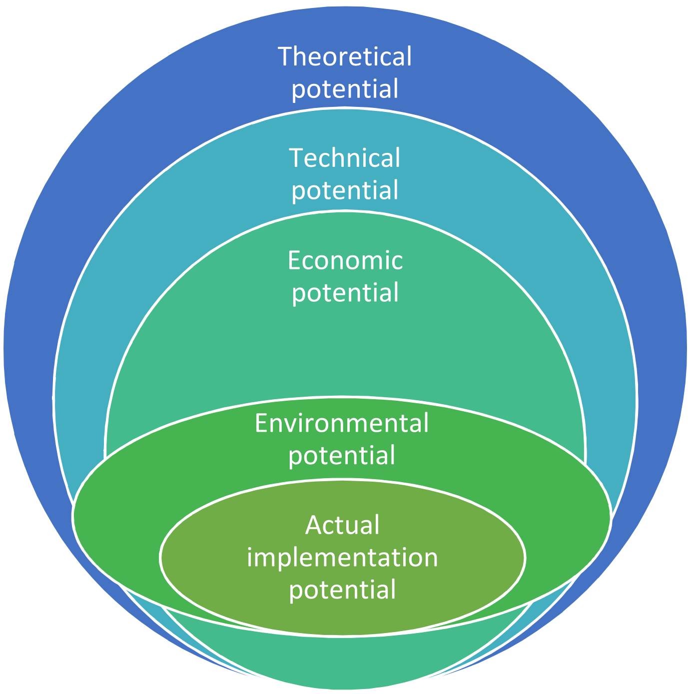

Figure 1: Biomass availability potentials

For the biomass assessments that were reviewed the following potential types were taken into account:

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Theoretical potential: the overall maximum amount of terrestrial biomass which can be considered theoretically available for bioenergy production within fundamental bio- physical limits.

Technical potential: the fraction of the theoretical potential which is available under the regarded techno-structural framework conditions and with the current technological possibilities, also taking into account spatial confinements due to competition with other land uses (food, feed and fibre production) as well as ecological (e.g. nature reserves) and other non- technical constraints.

Economic potential: the share of the technical potential which meets criteria of economic profitability within the given framework conditions.

Environmental potential: the fraction of the theoretical potential which meets ecologic criteria related to biodiversity as well as to soil erosion.

Actual implementation potential which represents the actual available biomass quantities

As shown in Figure 1 there are is a gradation for the theoretical to the actual implementation potential whereas there are overlapping relationships between the economic and the environmental potential, which means that environmentally sustainable biomass resources are not necessarily economic and vice-versa.

Biomass resources in this work include primary agricultural residues (straw, pruning, etc) and forest residues (fellings, branches, etc).

2.2 The Bioraise model

BIORAISE is a gis-based tool (http://bioraise.ciemat.es/Bioraise) that has been used for the calculation of potential and available agricultural and forest residues biomass in France, Greece, Italy and Spain. The methodological framework of this tool as well as the results that it can deliver are described in BeCool Deliverable 1.1 (https://www.becoolproject.eu/publications/).

2.3 Literature review biomass availability in Europe

Literature references were provided by the Brazilian partners in order to present the current biomass availability in Brazil. This work is preliminary and will be enriched at the end of the project in Deliverable D1.6, along with the biomass assessment in Europe.

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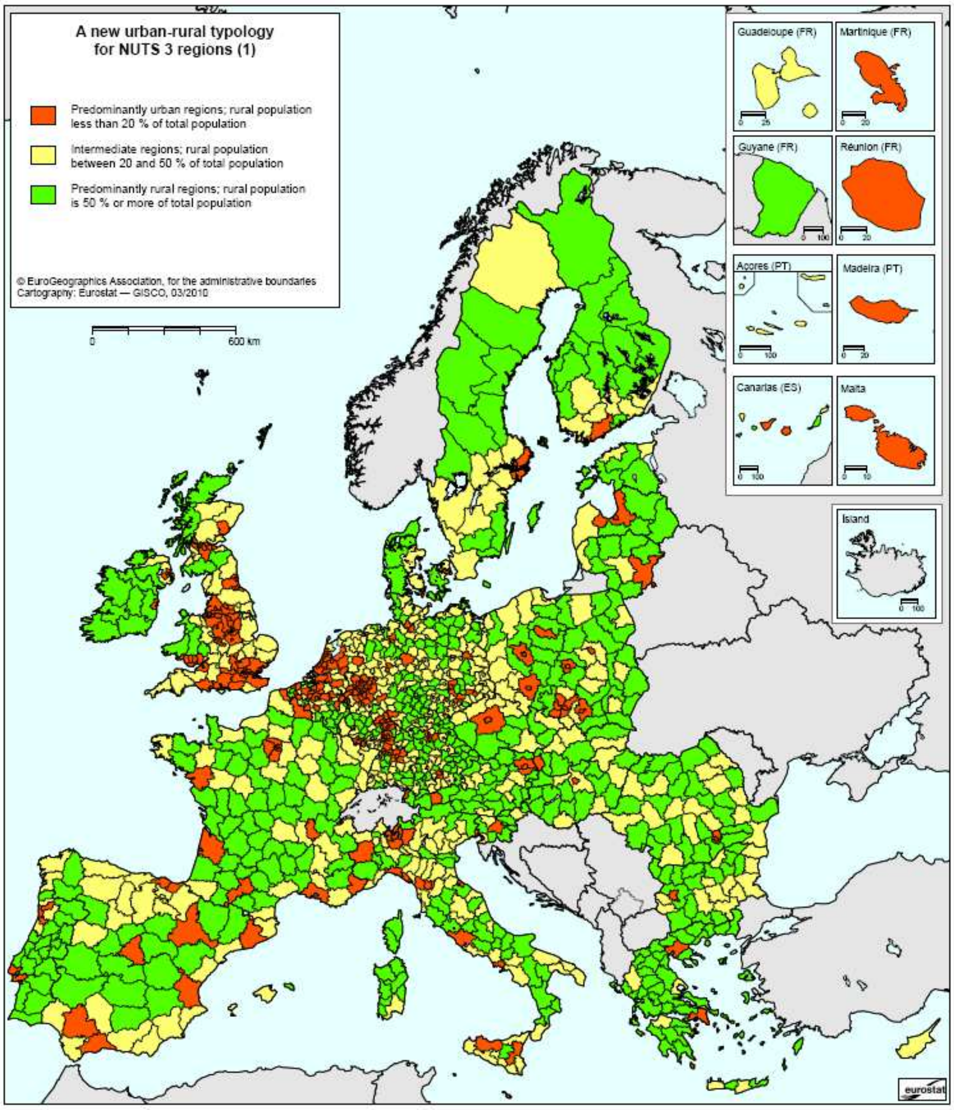
3. Results

3.1 The European agriculture profile

European territory is predominantly rural according to the European Union (EU) typology (Figure 2). Predominantly rural (PR) are the regions if the share of population living in rural local administrative units level 2 (LAU2) is higher than 50 %.



(1) This typology is based on a definition of urban and rural 1 km² grid cells. Urban grid cells fulfil two conditions: 1) a population density of at least 300 inhabitants per km² and 2) a minimum population of 5 000 inhabitants in contiguous cells above the density threshold. The other cells are considered rural. Thresholds for the typology: 50% and 20% of the regional population in rural grid cells.

For Madeira, Açores and the French outermost regions, the population grid is not available. As a result, this typology uses the OECD classification for these regions.

Figure 2: Urban-rural typology for NUTS 3 regions (Source: https://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:Urban-rural_typology)

European agriculture currently occupies 177.4 million hectares (about 39% of the EU's total land area) (EC, 2009) with 10.5 million holdings and employs about 9.7 million people.

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Agricultural holdings are constantly decreasing and in their majority they are small in size (<5 hectares per farm for the two thirds of the farms), usually family-owned and managed by male and relatively old famers (71.5 % of farmers were male and only 10.6 % were under the age of 40 years old in 2016 (EUROSTAT, 2018). Although the largest farms (>100 ha in size) correspond to the 3% of the farms they manage more than half of all (52.7) of the agricultural land.

The environment of Europe is largely differentiated. Metzger et al. (2005) elaborated a climatic stratification in thirteen environmental zones (Figure 3). The stratification was based on climate data, data on the ocean influence and geographical position (northing); soil data were not distinctive at the level of Europe, as the soil classification systems differ for each country.

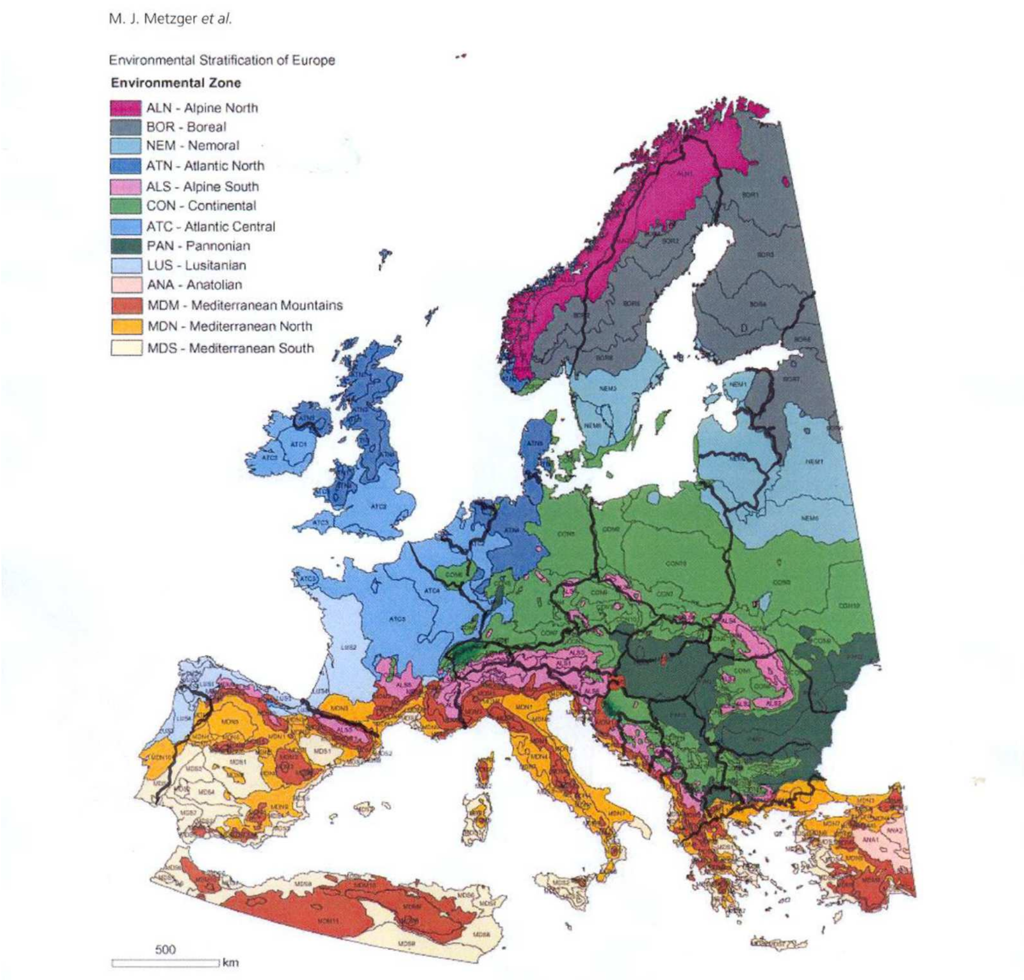

Figure 3: Environmental Stratification of Europe (Metzger et al, 2005)

Following the environmental constraints of each zone, the biomass types show large variations and so do the agricultural and forest residual forms that are available in each zone. Scarlat et al (2010) confirmed that there is large spatial and temporal variation in agricultural crop residue availability that is caused by the different geographic and climatic conditions and also by the agricultural practices. This variation was estimated at the range of +23% to −28% compared to average residue availability.

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3.2 Agricultural and forest residues available in Europe

Biomass is the largest single renewable energy source in absolute terms and represents around two thirds of the total primary energy supply of renewable energy sources in 2016, with 5,881 PJ according to IEA (2018). Hydropower amounts 1,260 PJ, wind energy 1,090 PJ, solar energy 560 PJ and geothermal energy 279 PJ.

According to the IEA report (Figure 4), the total primary energy supply of the 28 members of the EU in 2016 amounted to 66.9 exajoule (EJ) with bioenergy contributing 8.8% and 5.9 PJ.

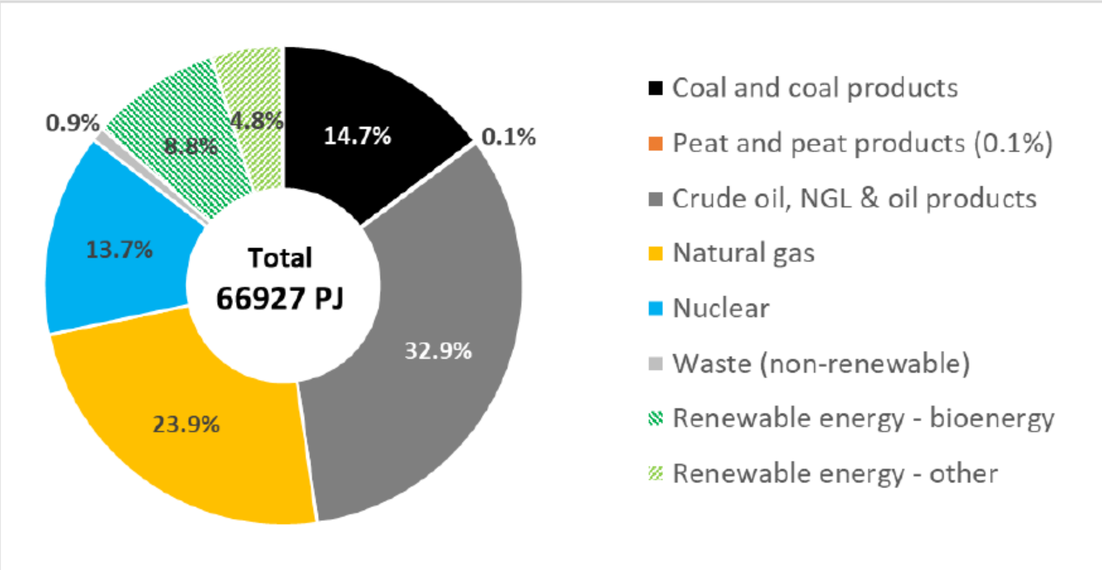

Figure 4: Total primary energy supply in the EU in 2016 (Source: World Energy Balances © OECD/IEA 2018 & https://www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_EU_final.pdf)

There is large variation in the estimated current and future potentials, which is subject to a number of parameters, like the different types of biomass resources covered (agricultural/forest residues), types of potentials (technical, economic, environmental, etc.), the geographic scope (EU or country level), scenario definitions and time frames as well as availability constraints (sustainability criteria, sustainable removal rate, competitive uses and alternative markets, etc.). In addition different terminology and units used in the reviewed studies further restrict the comparability of the results.

Agricultural residues that are available and meet the sustainability criteria range from 45 tons to 442 Mt dry matter until 2010, from 129 to 470 Mt in 2020, from 139 to 182 in 2030 and could reach 286 to 567 Mt dm in 2050 (Figure 5). Estimations were based on a Residue to Production Ratio (PRP) for each biomass source, which differs among the different biomass sources (straw, prunning, etc) and the various bibliographic references. Based on a lower heating value of 17.0 MJ kg^{-1} dry matter, these quantities would lead to annual sustainable energy potential that ranges from 0.7 to 7.5 EJ currently, from 1.9 to 8 EJ in 2020, from 1.9 to higher than 9 EJ for 2030-2040 time frames.

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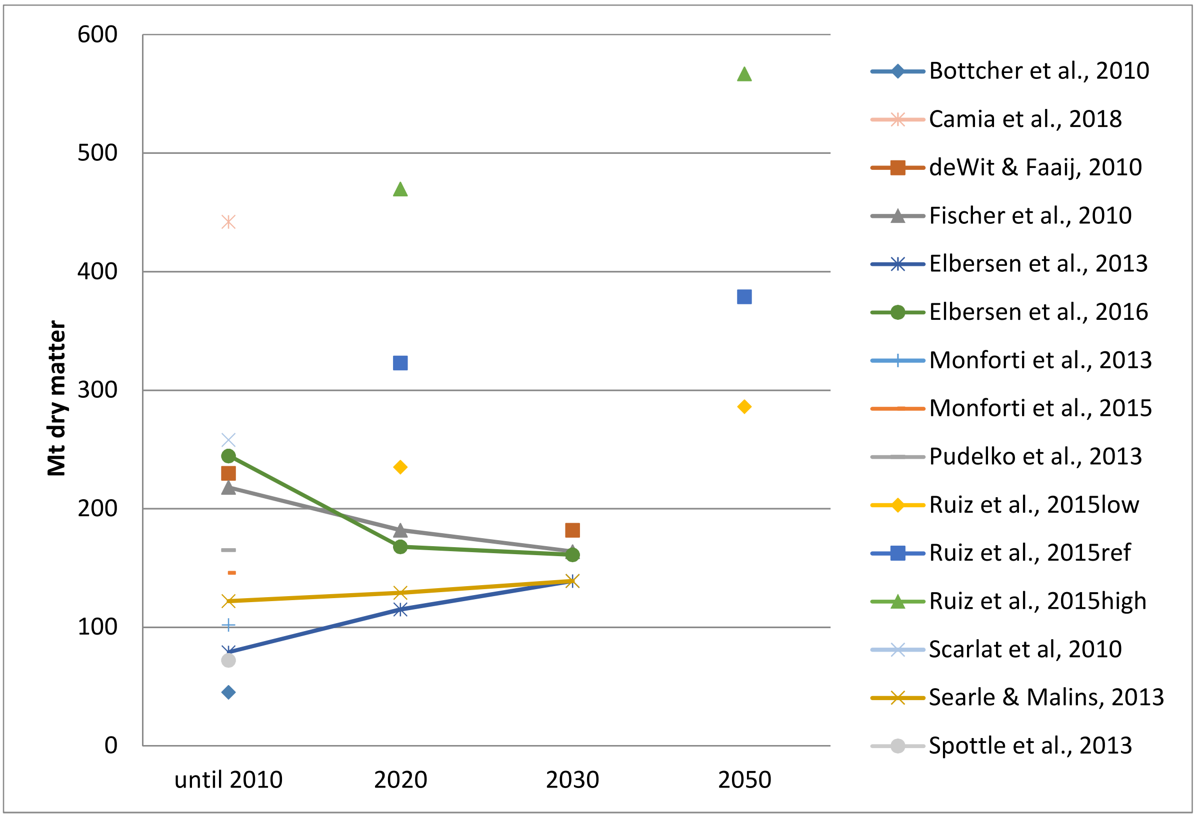

Figure 5: Availability of agricultural residues in the EU (Source: Kluts et al, 2017 modified)

In an extensive review made by Kluts et al (2017), it was revealed that the primary agricultural residues that are expected to play a key role in the future bioenergy scene are mainly cereal straw. Many studies are focused on straw availabilities from cereals and oil crops, and on maize stover (Botcher et al., 2010; de Wit& Faaij, 2010; Fischer et al., 2010; Monforti et al., 2013; Monforti et al., 2015; Scarlat et al., 2010; and Spottle et.al, 2013), while Elbersen et.al, 2013; Pudelko et al., 2013; Ruiz et al., 2015 and Searle and Malins, 2013 also include pruning residues.

As shown in Figure 5, the range of biomass potential assessments for 2010 is quite wide, whereas projections of primary residue availability after 2020 and 2030 remain more or less equal. The reason for this is mainly the Residue to Productivity Ratio (RPR) that, in some references (de Wit& Faaij, 2010; Fischer et al., 2010), is assumed low for the new and improved crop varieties leading thus to lower residues production, whereas others declare that higher crop yields per land unit will end up with higher residues production, since the residues used for soil protection is proportional to the land used (Monforti et al, 2015; Klutz et al, 2017).

In the majority of the countries wheat straw is the dominant straw type comprising over 60% of the total straw production, followed by barley, oat, rye and triticale, apart from Spain where barley straw accounts for the 55% of the total straw production (Spottle et al. 2013). Taking into account all types of the agricultural residues (including pruning) the total contribution of straw is estimated to be 91% and pruning 9% (Pudelko et al, 2013). Overall, wheat straw contributes the most (42%), followed by barley and maize (18%) and rapeseed and sunflower (6.9% and 5.2% respectively) to the total primary agricultural residues (Scarlat et al, 2010).

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Straw is produced in almost all EU countries, but larger countries have the higher potentials, like France, Germany, Poland, Italy, Hungary (Figure 6) (Elbersen et al., 2016). In Denmark there is the largest concentration of straw although the potential remains low because of the size of the country. Countries which show particularly large increases towards 2020 and 2030 are France, Poland, Hungary, Romania, UK and Denmark.

Straw however, apart from soil protection, is used for other competitive use, like animal bedding and feeding, horticulture, energy, other industrial uses i.e building materials, paper and pulp, thatching. Spottle et al. (2013) estimated that there is clear dominance of the livestock sector, which is estimated to use the 88.2% of straw, energy as the second most important user with 5.5% and horticulture with 4.8%. The rest 1.5% is used for other industrial uses.

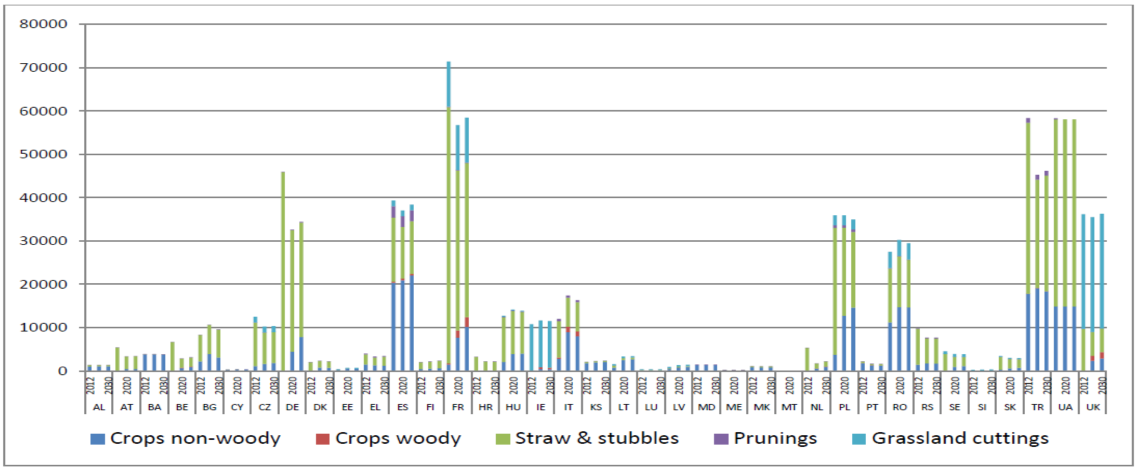

Figure 6: Total primary agricultural supply (kt dm) by country in 2012, 2020 and 2030 (Source: Elbersen et al., 2016)

Apart from straw and stubbles, pruning from fruit trees, citrus and olive trees and vineyards can deliver a significant potential, especially in the Mediterranean area (Elbersen et.al, 2016). Spain is the largest contributor followed by Italy, Greece and Portugal. The largest potential is delivered by vineyards and olives (Figure 6).

Forestry occupy 38% of the EU land and apart from the wood and wood residues provide a wide range of ecosystem services, like carbon storage and sequestration, soil erosion control, recreation, water regulation etc. (Camia et al, 2018). According to FAO (2001) forest is defined as the land with tree crown cover (or equivalent stocking level) of more than 10% and more than 0.5 ha, where the trees should be able to reach a minimum height of 5 m at maturity in situ. Among others, it includes forest nurseries and seed orchards that constitute an integral part of the forest, forest in national parks, nature reserves and other protected areas, plantations primarily used for forestry purposes, whereas the land either with a crown cover (or equivalent stocking level) of 5-10 % of trees able to reach a height of 5 m at maturity in situ, or a crown cover (or equivalent stocking level) of more than 10 % of trees not able to reach a height of 5 m at maturity in situ (e.g. dwarf or stunted trees); or with shrub or bush cover of more than 10 percent are considered as wooded land (FAO, 2001)

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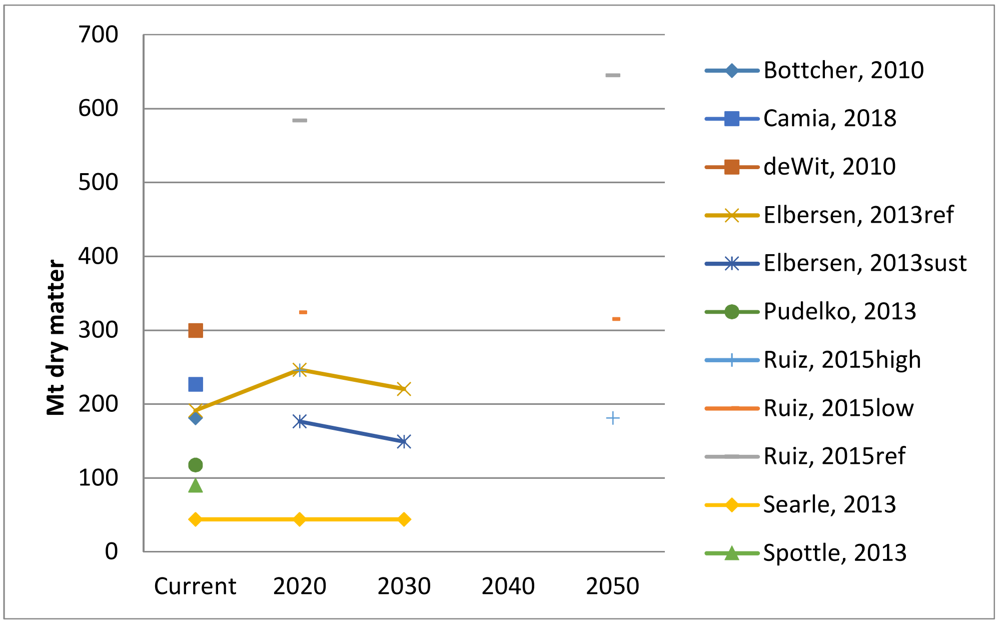

Figure 7: Availability of forest residues in the EU

The potential sustainable biomass production from forests consists of stem wood, primary forestry residues, e.g., logging residues, early thinnings and extracted stumps as well as secondary forest residues from wood processing industries.

Forest residues that are available and meet the sustainability criteria range from 44 tons to 500 Mt dry matter in 2010, to 584 Mt in 2020, and could reach more than 600 Mt dm in 2050 (Figure 7).

Scandinavia and Central France are the most important regions in the total round wood production but also small countries of the Baltic States, especially Latvia, have a significant production. The additional harvestable potential shows that in spite of the already high present stem wood production in most regions of Scandinavia and France they also contribute significantly to the still harvestable resource for bioenergy production. Other regions with a large contribution to the bioenergy feedstock potential are found in Italy, Romania and Slovenia. This latter group has clearly a large un-harvested potential in comparison to the present stem wood production (Elbersen, 2012).

The regions with a relatively large contribution to the primary forest residues are again concentrated in Scandinavia (Sweden and Finland), France, Italy, Germany but also in smaller countries like Austria, Czech Republic and Latvia, although this potential is generally much smaller than the additional harvestable potential (Elbersen, 2012). The four countries that have the largest forest biomass potentials (Sweden, Germany, France and Finland) represent about 45% of the total forest biomass potential (Dees et al, 2017).

Energy accounts for almost half (48%) of total reported uses of woody biomass on EU-28 level, as a result of the demanding renewable energy targets and the strongly growing consumption of pellets, among others (Camia et al, 2018).

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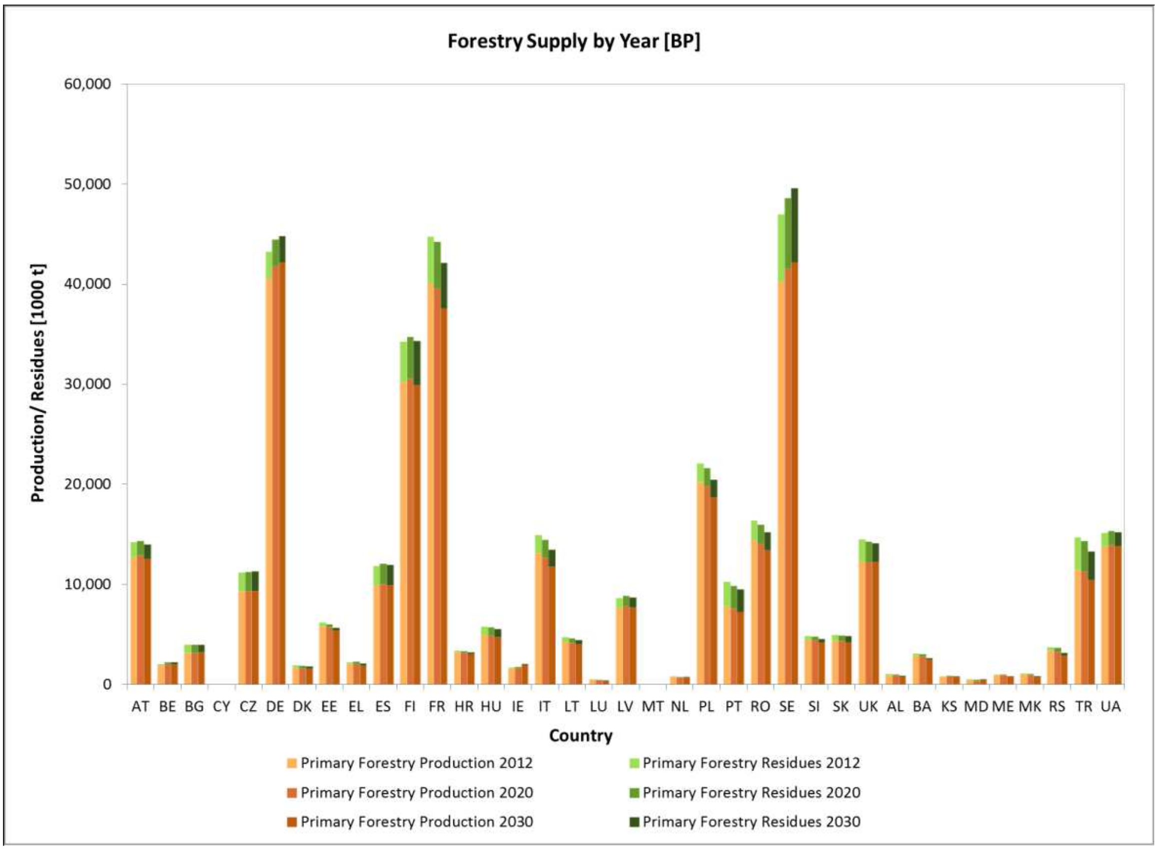

Figure 8: Primary forestry production by country for 2012, 2020, 2030 (Source: Dees et al, 2017)

3.3 Agricultural and forest residues available in Southern Europe countries (France, Greece, Italy and Spain) according to BIORAISE

The zones of interest for the BECOOL project are mainly the **Mediterranean North and South**, covering the southwest part of Europe (Spain, South France, Italy and Greece) and North Africa. It has short precipitation periods and long hot and dry summers. The length of the growing season is long and air temperatures favourable for growing a wide number of crops. However summer drought is a limiting factor that imposes the use of irrigation for crop survival and achieving high crop yields.

France lies partly in the **Atlantic Central** zone, which is influenced of the Atlantic Ocean, with rather low temperatures in summer and winter, abundant rainfalls and satisfactory length of growing period. The western part lies in the **Lusitanian** zone, which covers the southern Atlantic area and has rather high summer temperature and mild winters.

Potential and available surfaces are shown for agricultural residues in Table 1 and for forest residues in

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Table 2. Differences between the potential and available surfaces are mainly due to physical constraints which unable the collection of the biomass, this is common for forest areas and does not normally happen in agricultural areas, this is why both surfaces are equal for all type of biomasses in this case.

In Table 1 can be seen that rainfed crops (ie. cereals, sunflower) are the most important sources for agricultural residues production according to their surface, which account from 45% to 90% of the total agricultural area depending of the country. Olive surface is the second in order of importance for Spain, Italy and Greece with 20% to 30% of the total agricultural area, while for France vineyards come the second in order of importance with around 9%. The rest of the surfaces contributed together less than 30% to the total agricultural area of each country.

Table 1: Agricultural residues surfaces by type of biomass

	Biomass type	Country	Potential Surfaces (km^2)	Available Surfaces (km^2)
Agricultural Residues Origin	Rainfed crops	Spain	62641	62641
		Italy	26602	26602
		Greece	10345	10345
		France	108081	108081
	Rice	Spain	1137	1137
		Italy	2217	2217
		Greece	271	271
		France	192	192
	Orchards	Spain	10740	10740
		Italy	4175	4175
		Greece	1259	1259
		France	1463	1463
	Vineyard	Spain	9610	9610
		Italy	5270	5270
		Greece	750	750
		France	10932	10932
	Mix crops	Spain	286	286
		Italy	1366	1366
		Greece	23	23
		France	34	34

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	Olive	Spain	22385	22385
		Italy	9137	9137
		Greece	6953	6953
		France	NA	NA
	Irrigated crops	Spain	3575	3575
		Italy	246	246
		Greece	1887	1887
		France	NA	NA

The figures below show the NUTS 2 regions of France, Greece, Italy and Spain coloured in the areas were each biomass residue type is generated. For each agricultural residue a map filled with a different colour is shown from Figure 9 to Figure 15 as well as a map which includes all of them in Figure 16.

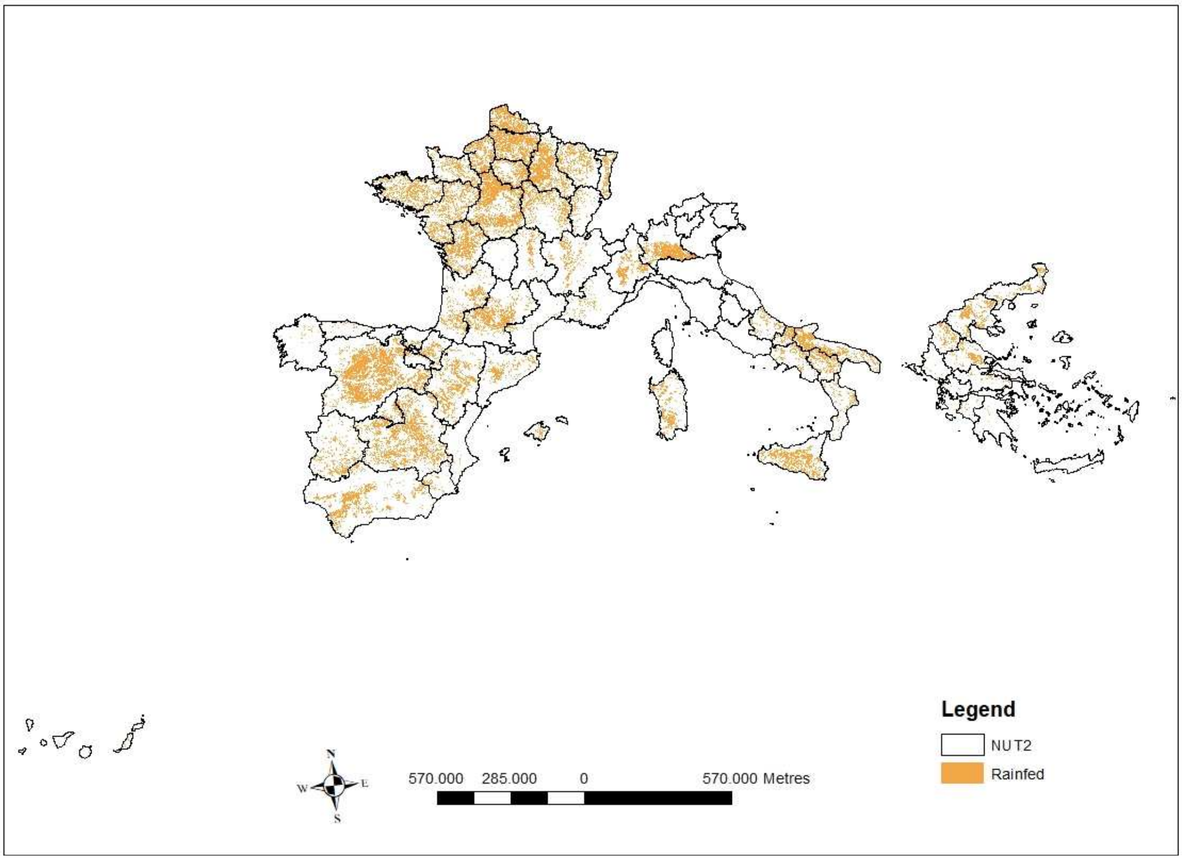

Figure 9: Rainfed crops area for NUTS 2 regions of Spain, France, Italy and Greece.

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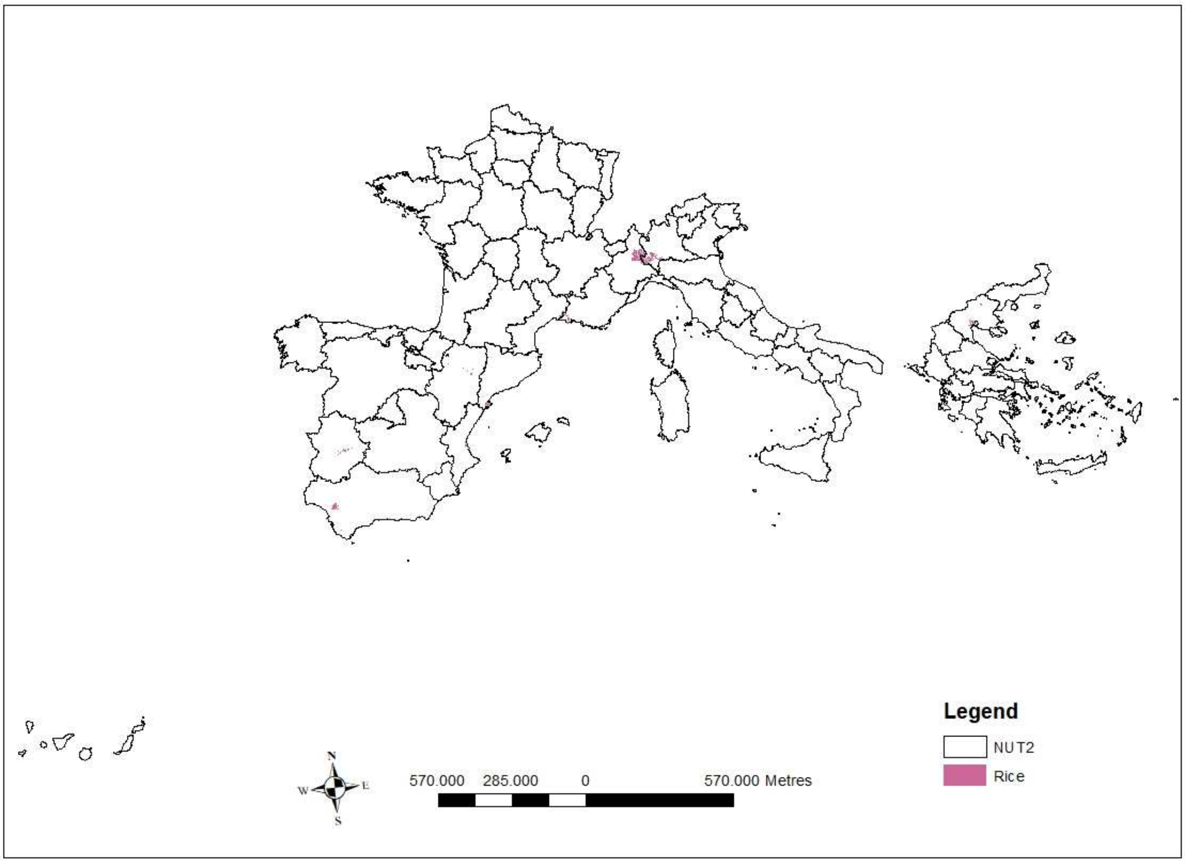

Figure 10: Rice area for NUTS 2 regions of Spain, France, Italy and Greece.

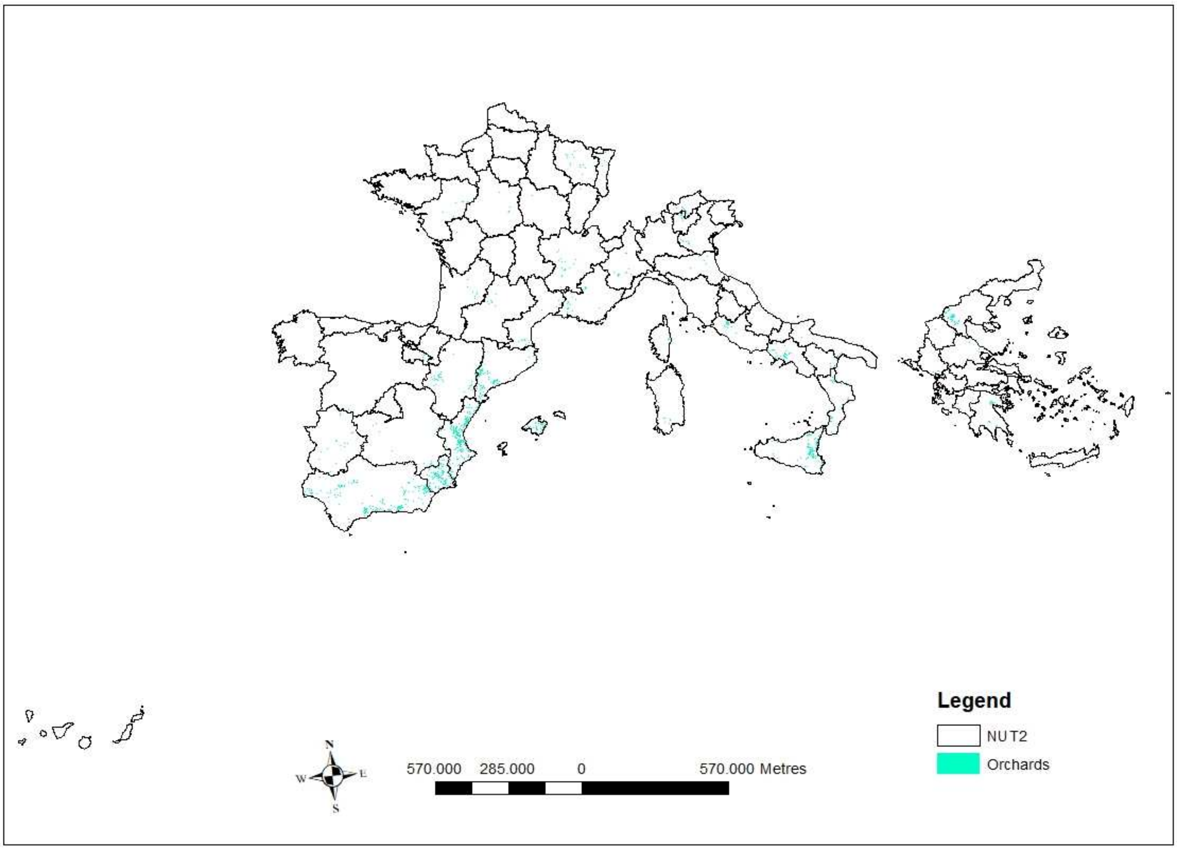

Figure 11: Orchards area for NUTS 2 regions of Spain, France, Italy and Greece.

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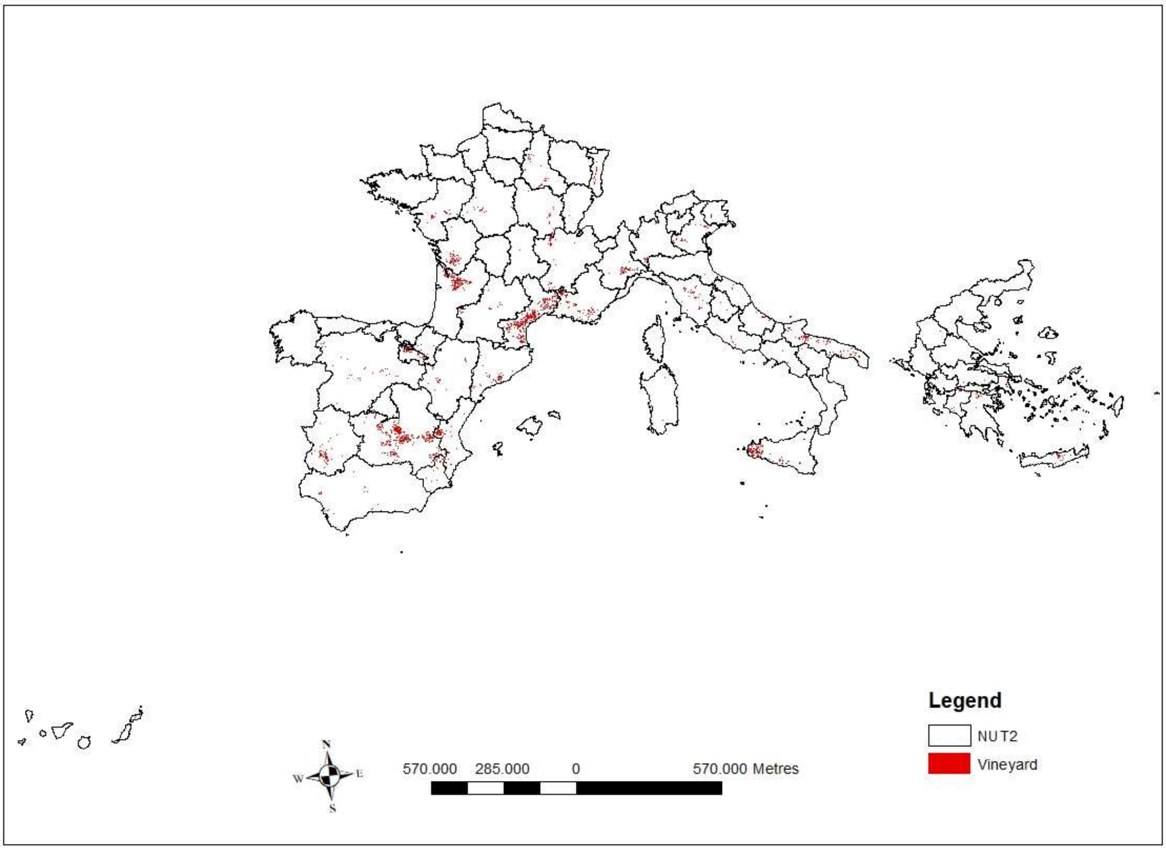

Figure 12: Vineyard area for NUTS 2 regions of Spain, France, Italy and Greece.

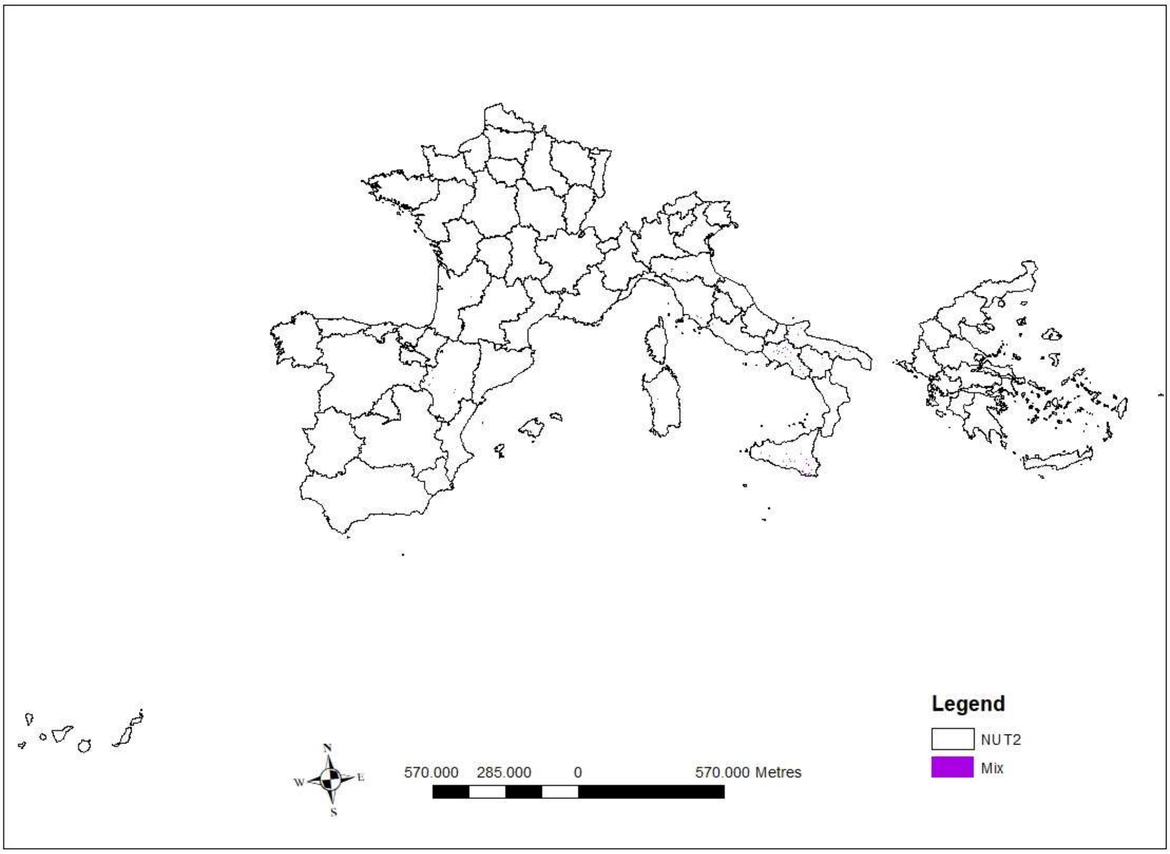

Figure 13: Mix crop area for NUTS 2 regions of Spain, France, Italy and Greece.

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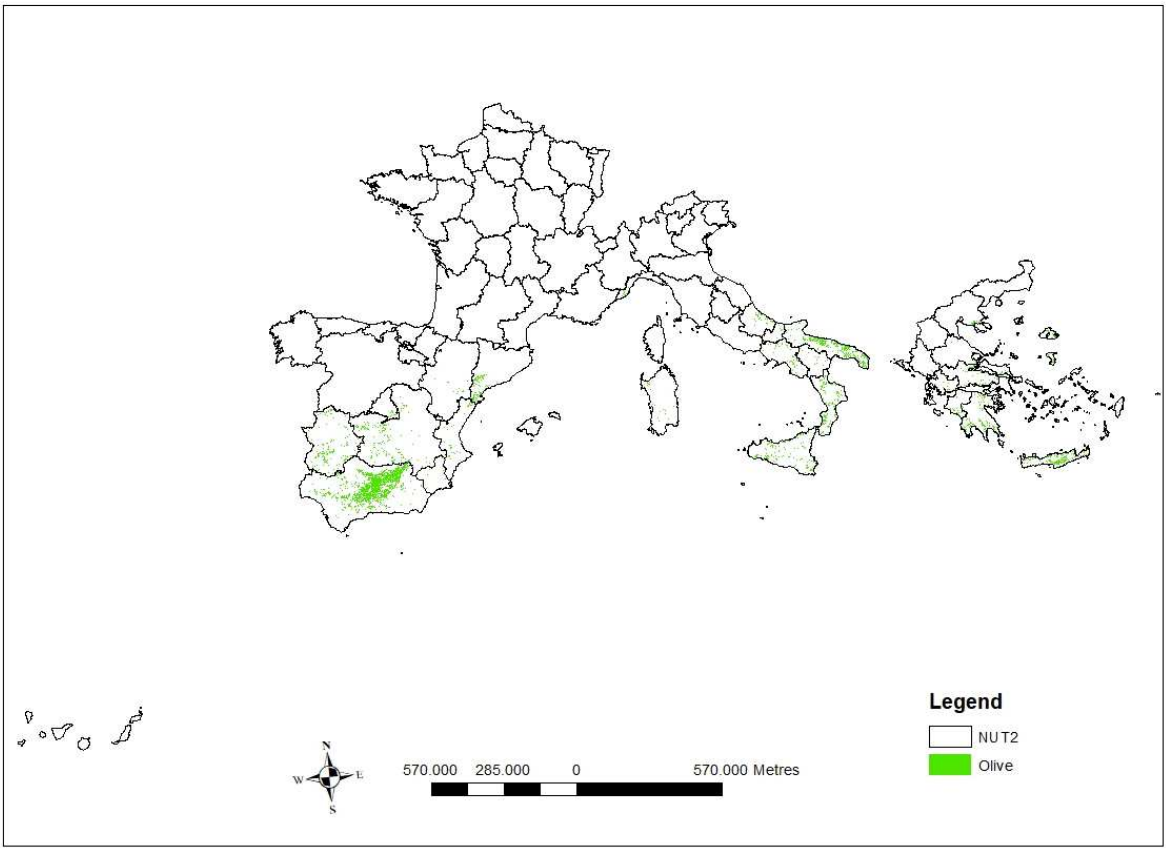

Figure 14: Olive area for NUTS 2 regions of Spain, France, Italy and Greece.

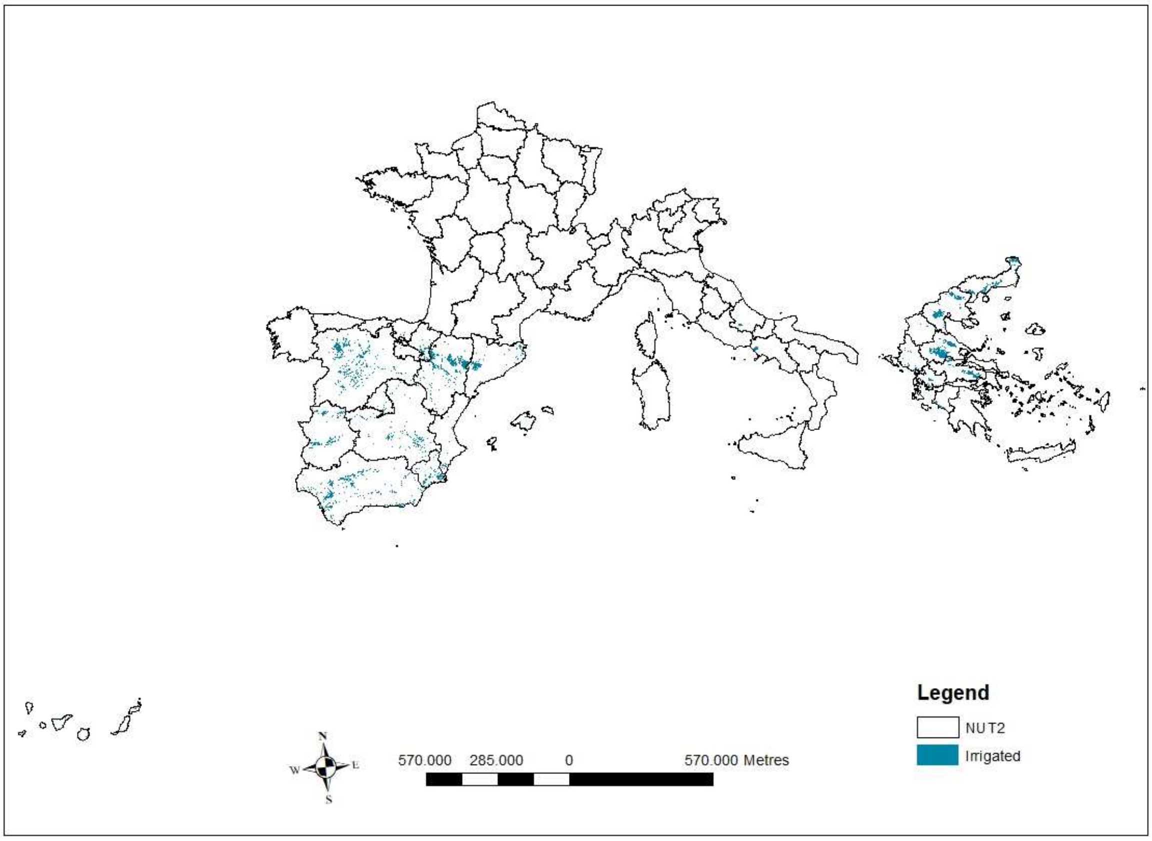

Figure 15: Irrigated crops area for NUTS 2 regions of Spain, France, Italy and Greece.

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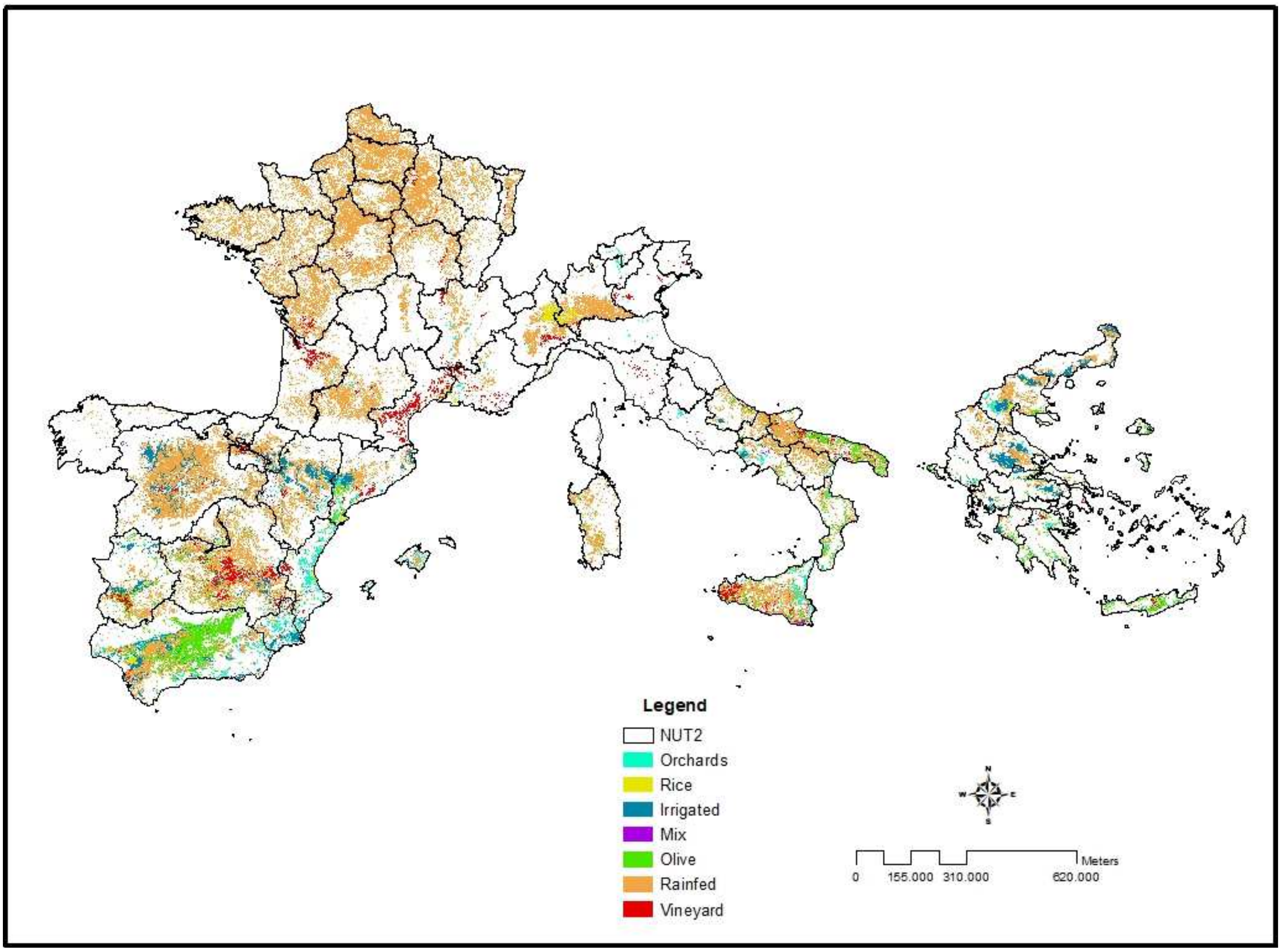

Figure 16: Agricultural areas of crops which produce residues for NUTS 2 regions of Spain, France, Italy and Greece.

Forest potential and available surfaces for residues production are shown in

Table 2

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Table 2. Broadleaved available surfaces are the first one in order of importance for the four countries covering the 40% to 70% of the total forest area, followed by conifers which occupy 15% to 30% depending on the country. These two types of forest surfaces account together for 80% to 85% of the total forest area and therefore are much more important than mixed and agro-forestry areas.

Table 2: Forest residues surfaces by type of biomass

	Biomass type	Country	Potential Surfaces (km^2)	Available Surfaces (km^2)
Forest Residues Origins	Broadleaved	Spain	39201	37513
		Italy	47746	47038
		Greece	10147	9817
		France	56364	51795
	Conifers	Spain	38116	36419
		Italy	11889	11747
		Greece	6254	6056
		France	29460	28591
	Mixed	Spain	11233	10707
		Italy	9678	9502
		Greece	4280	4069
		France	15975	15252
	Agro-Forestry	Spain	12230	9177
		Italy	1436	1399
		Greece	NA	NA
		France	2	2

In Figure 17 and Figure 18 the potential and available biomass by country of origin are shown for agricultural and forest residues.

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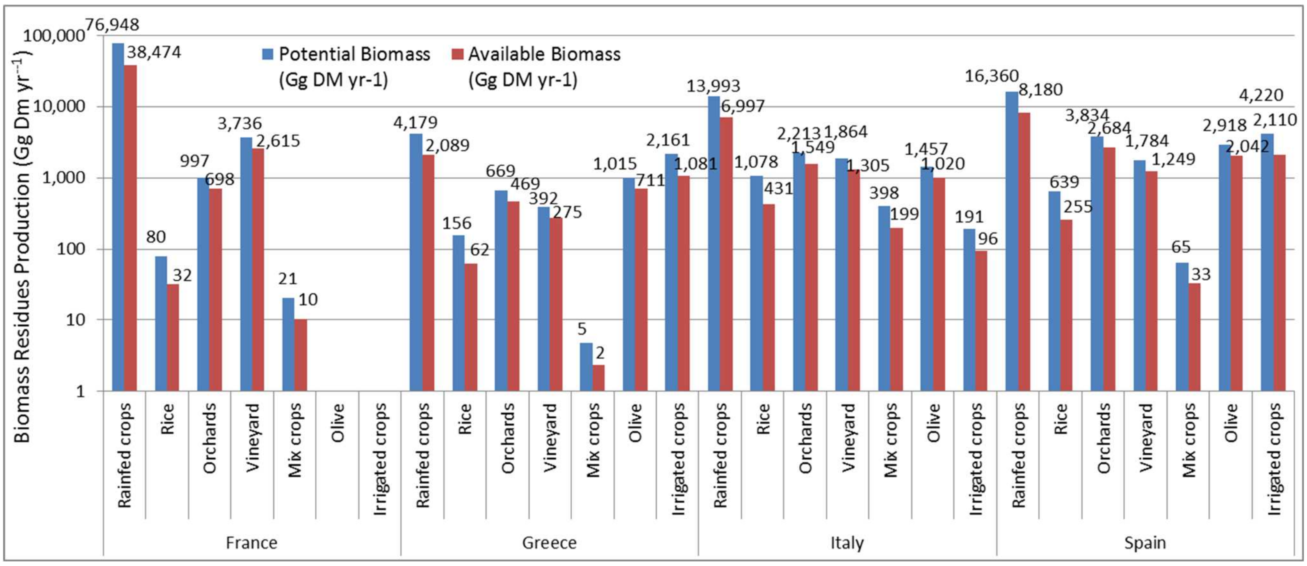

Figure 17: Agricultural residues potential and available biomass by country of origin.

It can be observed in Figure 17Figure 1 that for France the available residual biomass from rainfed crops is predominant with a 92% of the total biomass production. For Greece, these crops account for 45% while irrigated crops with 23% and olives with 15% having also an important contribution in this case. In Italy, rainfed crops are also the most important one with a production of available residual biomass of 60% followed by orchards (13%), vineyards (11%) and olives (9%). In Spain, as in the previous countries there is a predominance of residue from rainfed crops which accounts to 50% of the total agricultural residues, followed by an equally important contribution of orchards (16%) and olives (12%) but also a remarkable influence of irrigated crops with a 13%.

Figure 18 shows that for France, the available forest residues produced from broadleaved species are predominant with a 51% while conifers and mixed areas are also important with a 32% and a 17% of residues production respectively. In Greece, broadleaved species produce 57% of the available residues while conifers and mixed areas around 20% each. Similarly as in previous countries there is a predominance of broadleaved species for Italy with a 64%, followed by conifers with 20% and mixed areas with 15%. In Spain broadleaves also produce the highest quantity of available residues with a 51% followed by a 32% of conifers, 12% of mixed areas and a remarkable 5% contribution of agroforestry lands.

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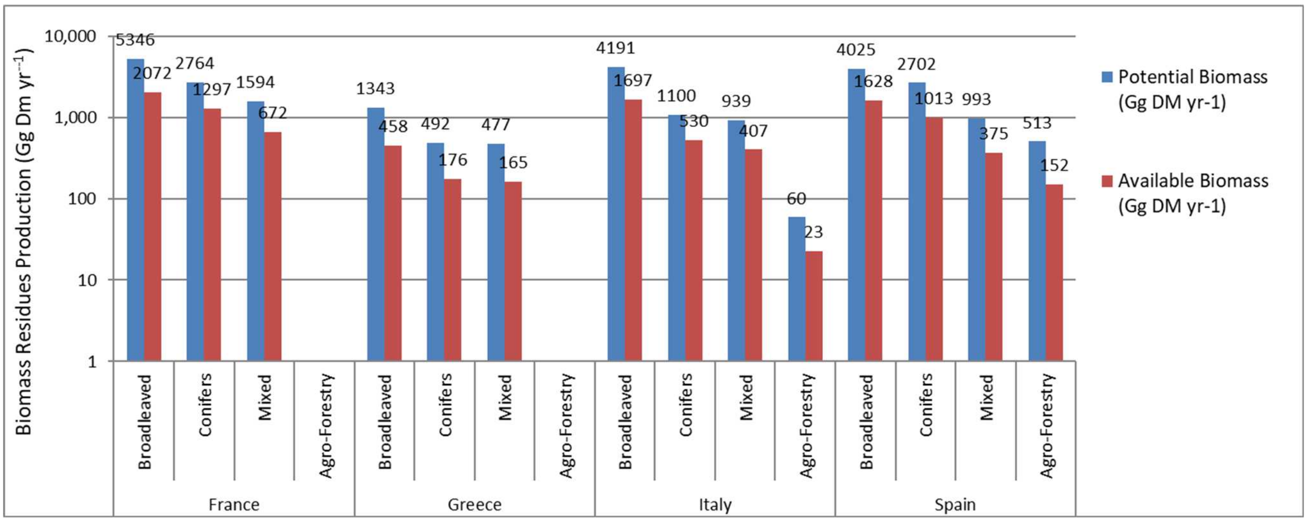

Figure 18: Forest residues potential and available biomass by country of origin.

Figure 19 and Figure 20 show potential and available forest and agricultural residues by type of biomass.

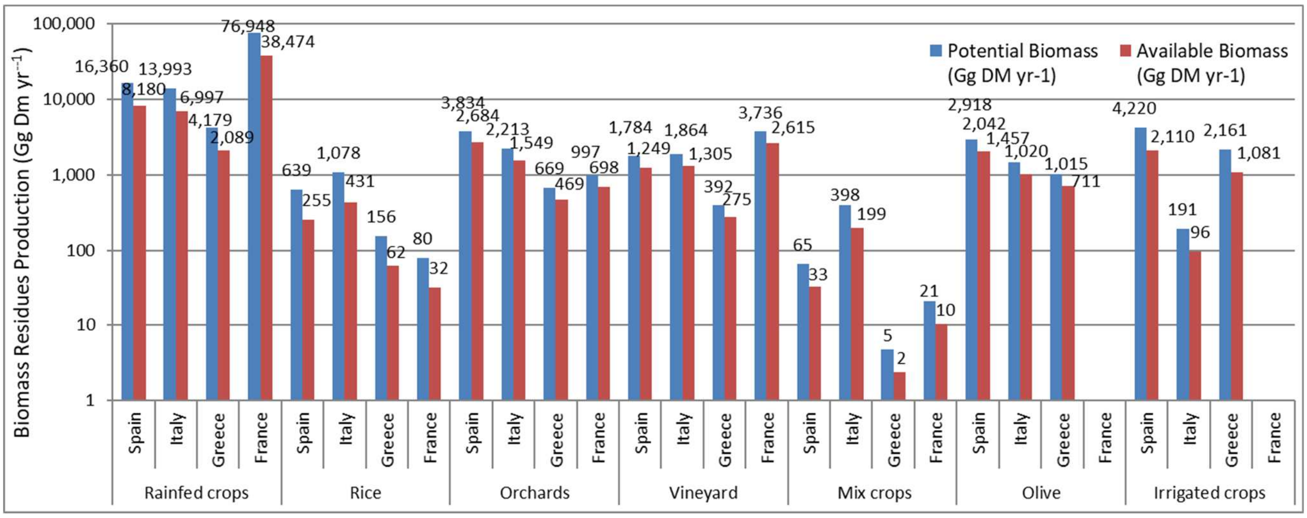

Figure 19: Agricultural residues potential and available biomass by biomass type.

In Figure 19 can be seen that France is the highest producer of biomass available residues from rainfed crops (69%) and vineyards (48%), while Italy is for rice (55%) and mix crops (81%) and Spain is for irrigated crops (64%), olives (54%) and orchards (50%).

Figure 20 shows that available residues produced from broadleaved species are not much different for France (35%), Spain (29%) and Italy (28%). For conifers France has the highest contribution with 43% followed by Spain with a 34%. In mixed areas France is predominant (42%) while Spain is for agroforestry (87%).

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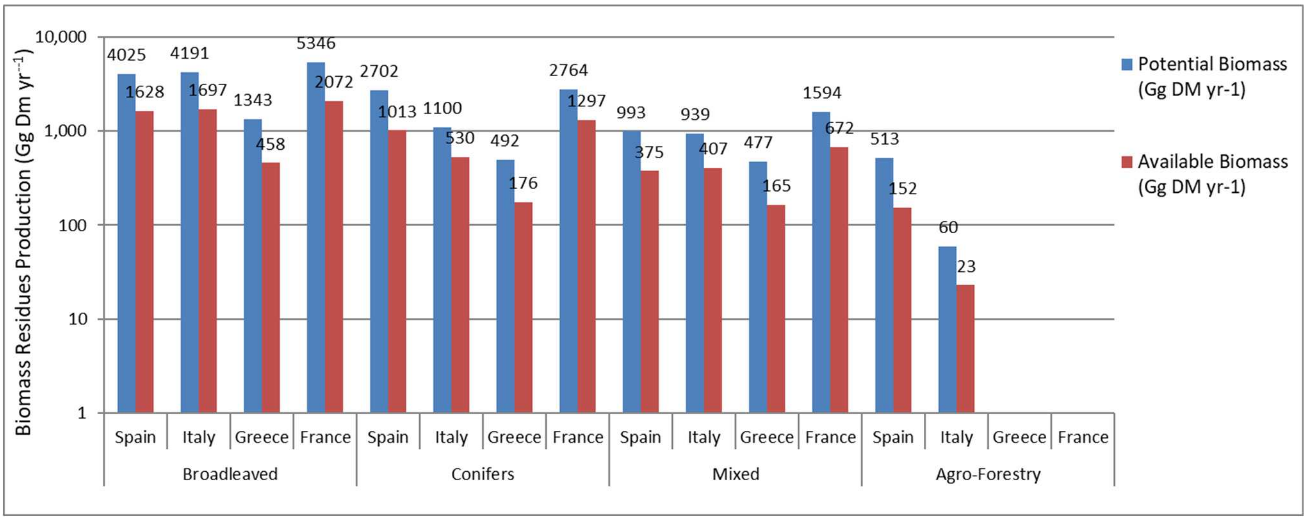

Figure 20: Forest residues potential and available biomass by biomass type.

Total available residues for the four countries account for 85333 Gg D.M.·yr^{-1} (87% agricultural) with France as the highest contributor with 45870 Gg D.M.·yr^{-1} (91% agricultural), followed by Spain with 19722 Gg D.M.·yr^{-1} (84 % agricultural), Italy with 14253 Gg D.M.·yr^{-1} (81% agricultural) and Greece with 5488 Gg D.M.·yr^{-1} (85% agricultural).

Forestall surfaces by type of residue are shown from Figure 21 to

Figure 24 and all of them together in Figure 25.

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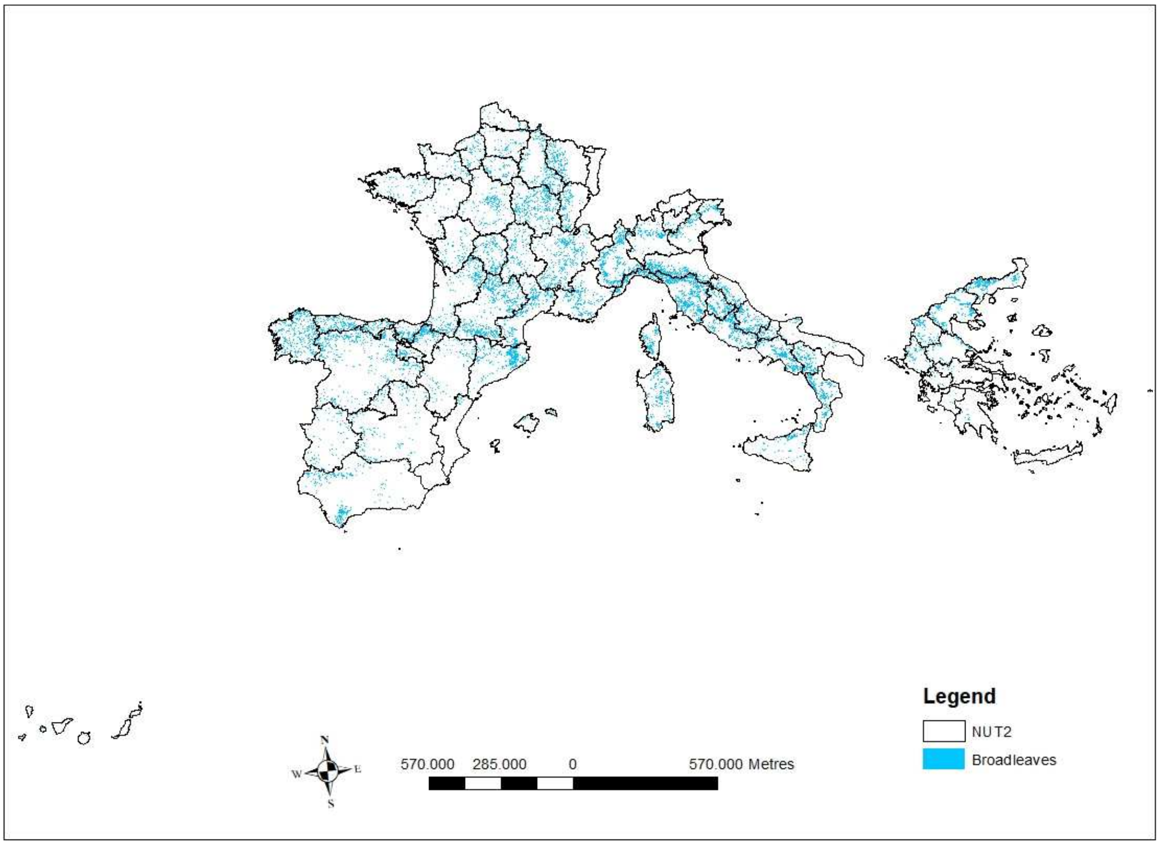

Figure 21: Broadleaved species area for NUTS 2 regions of Spain, France, Italy and Greece.

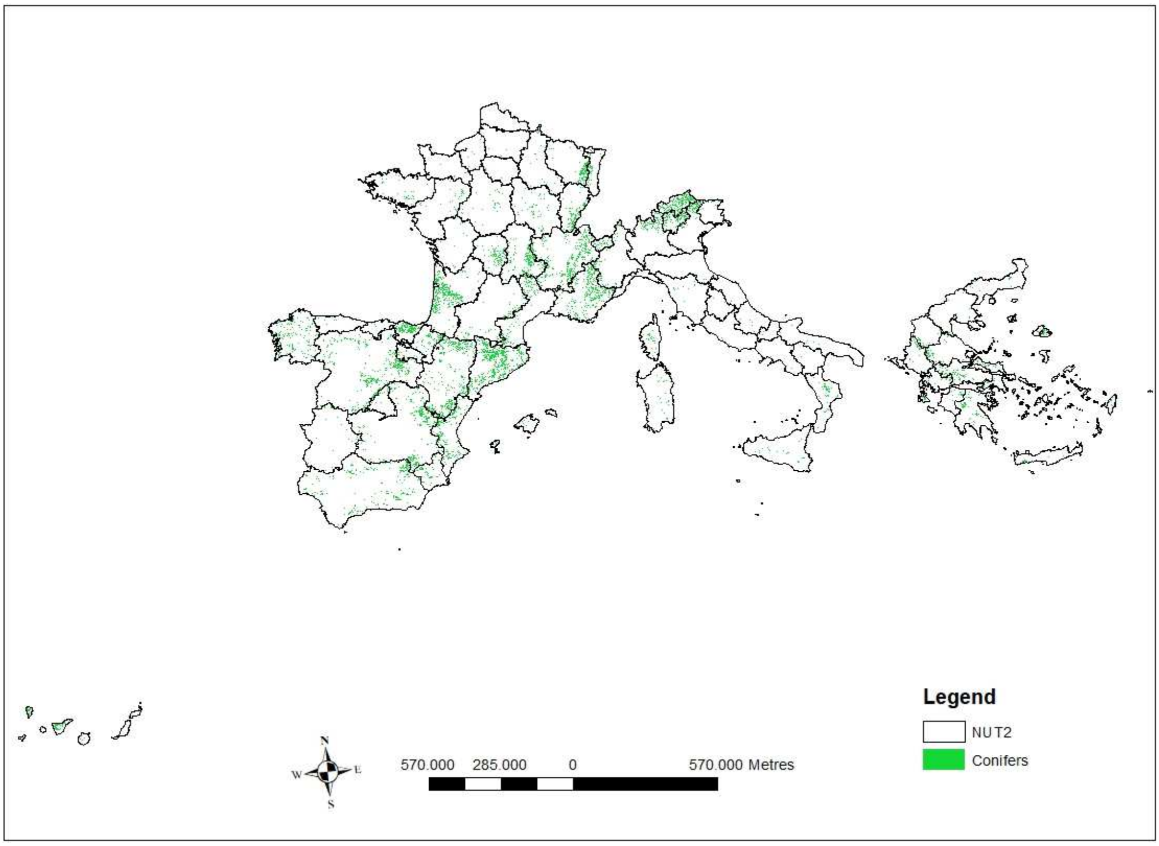

Figure 22: Conifers area for NUTS 2 regions of Spain, France, Italy and Greece.

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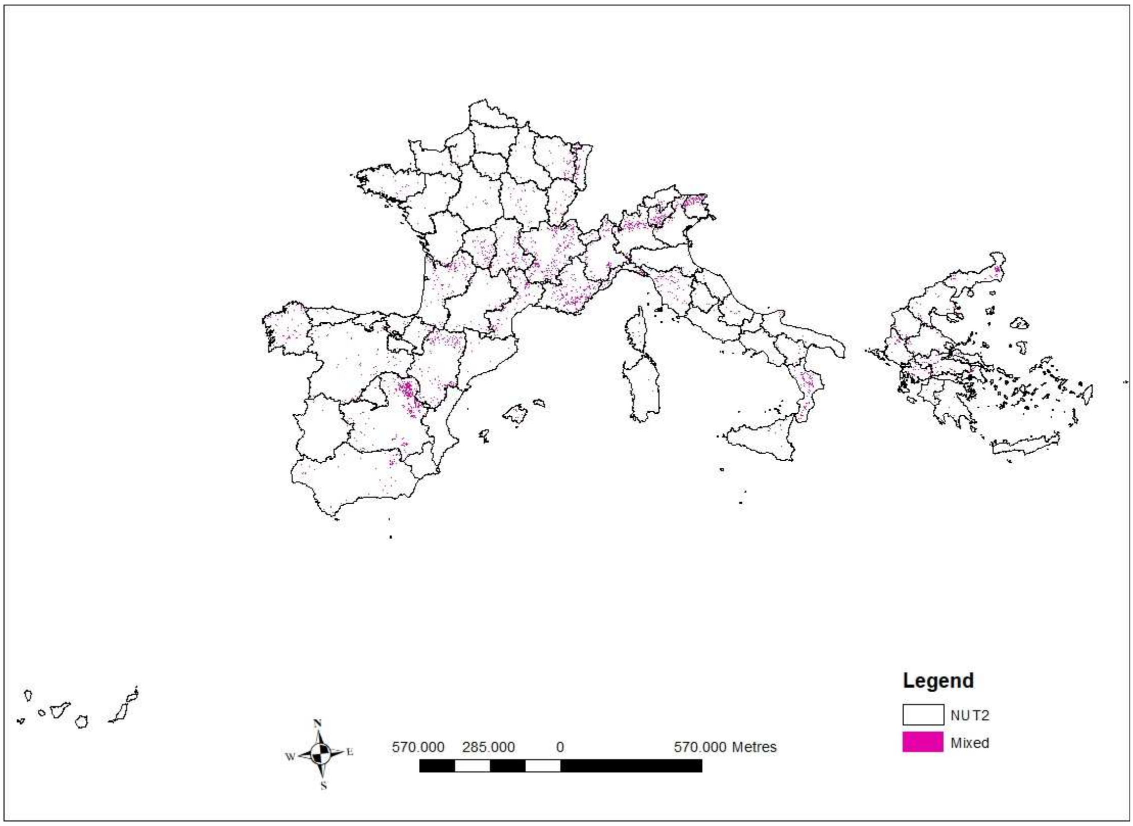

Figure 23: Mixed forest species area for NUTS 2 regions of Spain, France, Italy and Greece.

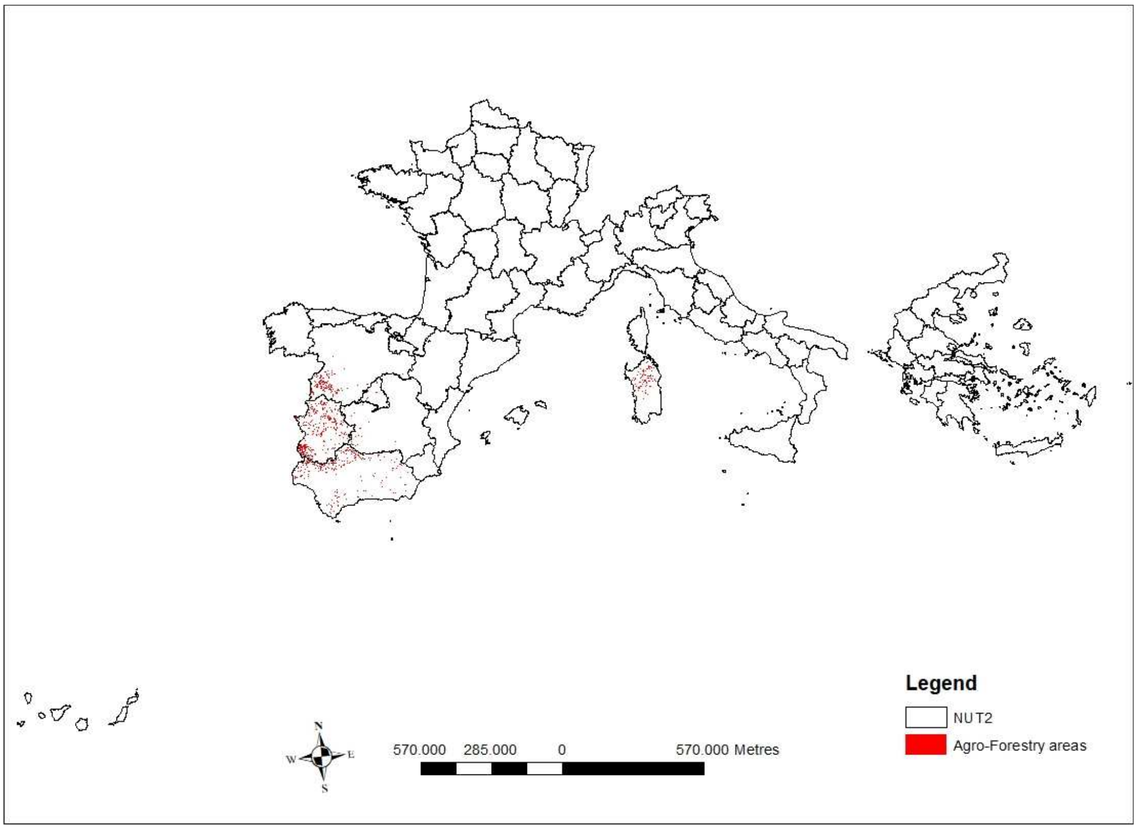

Figure 24: Agroforestry area for NUTS 2 regions of Spain, France, Italy and Greece.

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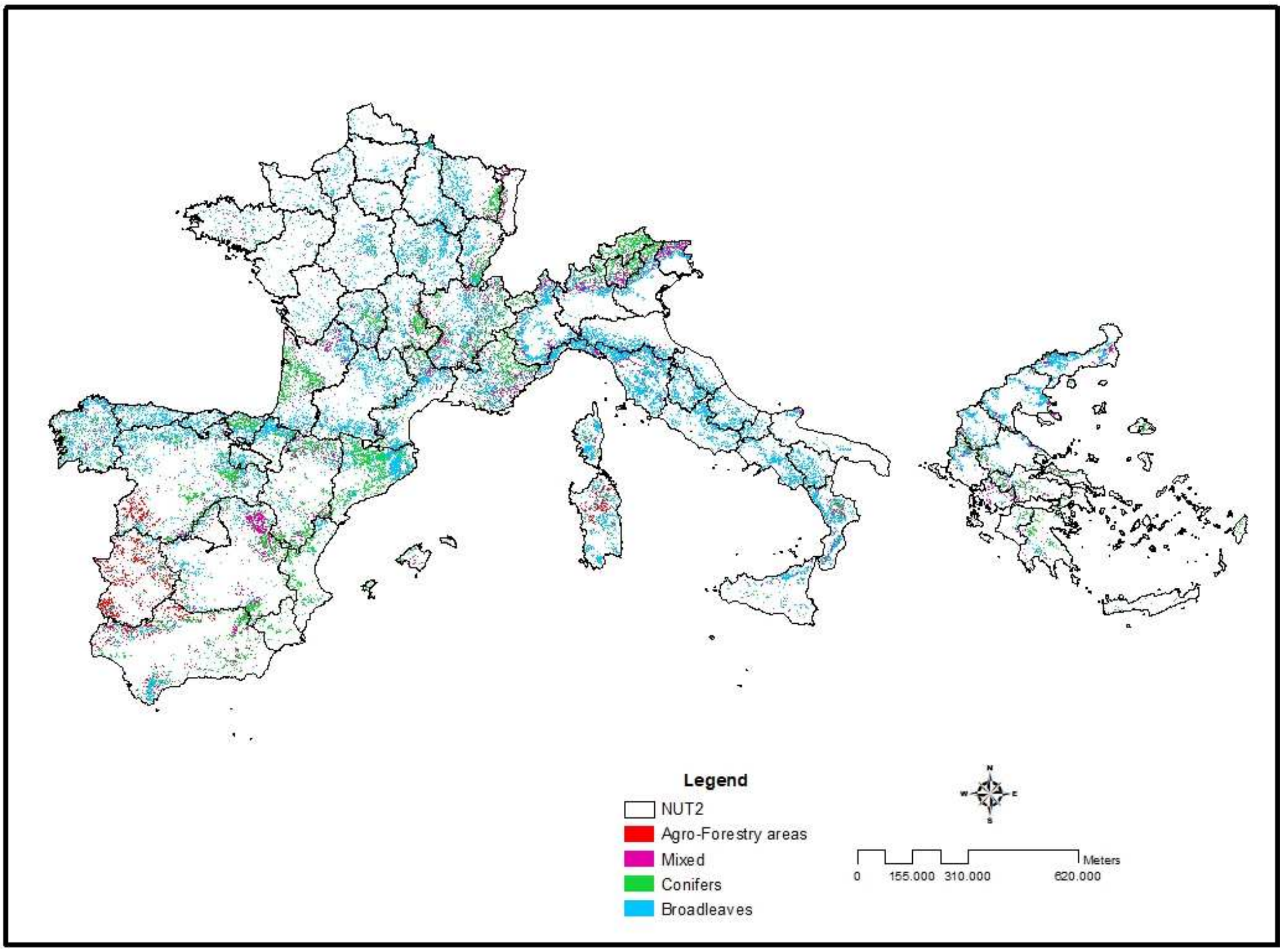

Figure 25: Forest areas of species which produce residues for NUTS 2 regions of Spain, France, Italy and Greece.

3.4 Agricultural and forest residues available in Brazil

During the past three decades, Brazil's agriculture sector has grown at an impressive rate 105.7% compared to -5.5% and 11.7% in the manufacturing and service sectors respectively, between 2000-2013, mainly due to two sets of public policies (i) investments in innovation, and (ii) trade liberalization (Arias et al, 2017). Agriculture productivity growth has also led to significant increases in the value of agriculture production.

Brazil is a major player in global agricultural trade, being currently the world's largest producer of sugarcane, which accounts for almost the 40% of the global sugarcane production (FAO, 2017; Carvahlo et al, 2019; Cherubin, 2019), and the world's third-largest exporter of agricultural products, after the EU and the United States (FAO 2014). Soybean products remain the largest export, followed by sugarcane products (sugar and ethanol), meat (especially poultry and beef), coffee and cereals.

In 2018/2019, sugar cane was cultivated in 10.1 million hectares, and produced 29 million tons of sugar and 33 billion litters of ethanol (Cherubin et al, 2019). The 92% of which is concentrated in central southern Brazil and the 57% only in the state of Sao Paolo, (Gonzaga et al, 2019; Cherubin et al, 2019). Sugarcane production represents the 15.2% of the total agricultural production value in Brazil, with the respective soybean

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production representing more than 37% (Figure 26). Soybean, sugar cane and corn made up approximately 63% of the country's agricultural production value that year (Statista, 2018). Agricultural residues are reported to reach 597 million tons per year (Ferreira-Leitao et.al, 2010).

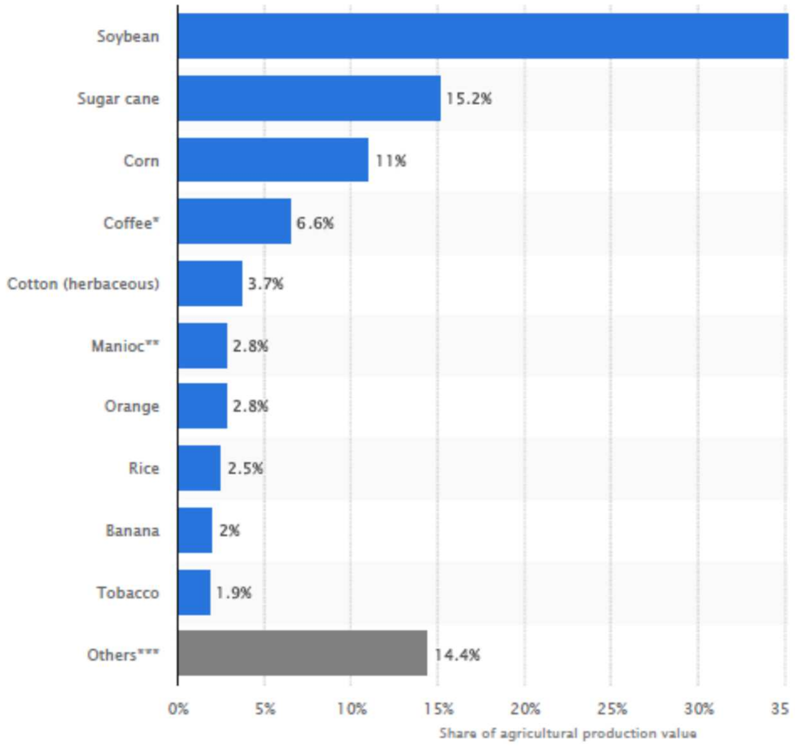

Figure 26: Agricultural production in Brazil 2018, by crop

Sugarcane production more than doubled over the last decades to meet the extensive demands for bioethanol production. The major environmental results of such rapidly expanding sugarcane production over land use change and food security were reviewed by Brazilian scientists (Bardonal et al, 2018). Their conclusion was that sugarcane plantations did not contribute to direct deforestation, and their expansion on degraded pastures along with the expected increased yields of food crops and livestock intensification decreased land competition between food and sugarcane, provided that sustainable agricultural practices are followed. Such practices mainly refer to non-burning/mechanical harvesting, nitrogen inputs, water consumption.

A usual practice for sugarcane harvesting was the burning of sugarcane straw before harvest, which was causing serious health problems (asthma, respiratory problems, lung cancer etc,) as well as GHG emissions (Bardonal et al, 2017). In the latter study it was reported that emissions of 941 kg CO2eq ha^{-1} $year^{-1}$, which corresponds to 30.3% of total GHG emission related to sugarcane agricultural production, are being released by the sugar cane burning.

With the prohibition of burning prior to harvest, in the recent years sugarcane harvesting shifted towards the so-called green mechanized harvest without burning, in which a large amount of sugarcane straw is left in the field (10 - 20 t ha^{-1} of dry straw). Currently, around 96% of the sugarcane fields in São Paulo state are mechanically harvested without burning (Gonzaga, 2019). The mechanical sugarcane harvesting is a win-win

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strategy in agronomic and environmental terms, apart from soil compaction caused when the heavy harvesters work in the fields (Bardonal, 2017).

Keeping straw on the soils after sugarcane harvesting has several beneficial effects, such as maintenance of soil moisture and nutrients, avoidance of water losses and nutrient leaching, protection against soil erosion, increase of the microbial community of the soils and soil carbon, etc. However, it is not certain how much straw has to be kept on the soil to enhance its fertility and how much to be removed for further uses, including bioenergy. A number of studies have been performed to answer that question.

According to Cheroubin et al (2019), maintaining top leaves in the field and harvesting only bottom leaves has the less impact of soil nutrients (NPK) removal; whereas total straw removal could double NPK-fertilizer consumption in sugarcane fields by 2050.

Sugarcane is highly efficient in terms of nitrogen use efficiency, which is an important factor for its high energy balance. But, special attention should be given regarding emissions of nitrous oxide when straw mulching is combined with application of nitrogen fertilizer and vinasse (Bardonal et al, 2017).

Gonzaga et al (2019) studied the implications of straw removal for soil N_2O and CH_4 emissions derived from nitrogen (N) fertilization in São Paulo state, Brazil. It was clearly evidenced that CH_4 fluxes were very low regardless of straw removal rates, indicating a predominance of CH_4 consumption by the soil. Straw removal was found to reduce N_2O emissions, a clearly site-specific effect, which however in other studies (Carvahlo et al, 2017) is associated with the application of N fertilizer and vinasse. An appropriate recommendation, which is clearly site specific, should be based on a minimum mass of straw on the field to provide those benefits. Overall, Carvahlo et all, indicated that most of the agronomic and environmental benefits are achieved when at least 7 Mg ha^{-1} of dry straw is maintained on the soil surface.

Furthermore, several studies reported higher sugarcane production under straw retention on the field, while few suggest that straw may jeopardize biomass production in cold regions and under some specific soil conditions. Straw removal affected sugarcane yields in a variety of soil types, but this effect was more site specific and higher responses were observed under best conditions for sugarcane growth (Carvahlo et al, 2019). In this study it was also declared that harvesting season has a relevant role on determining yield responses to straw removal and younger ratoons are more responsive to straw removal.

Straw removal long-term effects on soil organic carbon (SOC) and sugarcane yield on contrasting edaphoclimatic conditions in Brazil was also high in the research agenda. Tenelli et al (2019) concluded that neither tillage practices nor straw removal alone significantly affected sugarcane yield on sandy loam soil, but certain combinations showed substantial yield reductions on clayey soil. Overall, each ton of straw returned to the soil increased SOC stock by 95 kg ha^{-1} for clayey soil under both tillage practices and 55 kg ha^{-1} for sandy loam under the conventional tillage system. Furthermore, straw removal decreased microbial biomass C and b-glucosidase activity. They suggest that the adoption of reduced tillage attenuates the adverse impacts of straw removal on SOC stocks while ensuring sugarcane yields for a more sustainable bioenergy production in Brazil.

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4. Conclusions

Biomass resource estimations are diverse and sometimes contradictory because final targets, models and assumptions are diversified. It is expected that the availability of primary agriculture and forest residues will remain stable between now and 2030. In all studies, straw is the dominating agricultural residue. Agricultural residues that are available and meet the sustainability criteria are reported to range from 45 tons to 442 Mt dry matter until 2010, from 129 to 470 Mt in 2020, from 139 to 182 in 2030 and could reach 286 to 567 Mt dm in 2050.

The potential sustainable biomass production from forests consists of stem wood, primary forestry residues, e.g., logging residues, early thinnings and extracted stumps as well as secondary forest residues from wood processing industries. Forest residues that are available and meet the sustainability criteria are reported to range from 44 tons to 500 Mt dry matter in 2010, to 584 Mt in 2020, and could reach more than 600 Mt dm in 2050.

In the four countries in our study, France, Greece, Italy and Spain, the total available residues account for 85.3 Mt dm/y (87% agricultural). Straw from rainfed cereals is the dominating the agricultural residue whereas broadleaves followed by conifers account together for 80% to 85% of the total forest area. Optimized logistics could significantly increase the energy exploitation of the residual biomass types.

Energy crops can be a significant asset to increase biomass feedstock that would be able to cover high biomass needs. However, stricter sustainability constraints on biodiversity conservation and GHG emissions will hinder their development. Studies showed among others a shift in shares from annual to perennial energy crops, due to the applied sustainability constraints; the stricter they are the higher share of perennials will be.

In Brazil, sugarcane production represents the 15.2% of the total agricultural production value, with the respective soybean production representing more than 37%. Soybean, sugar cane and corn made up approximately 63% of the country's agricultural production value that year. Agricultural residues are reported to reach 597 million tons per year.

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