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Biomass Potential from Agricultural Waste for Energetic Utilization in Greece

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Abstract: The alignment of the Greek national legislation with the corresponding EU legislation has enhanced the national efforts to pursue renewable Combined Heat and Power (CHP) projects. The scope of the present study has been the identification of the available biomass resources and the assessment of their potential. In this paper, we present the results from the administrative regions of Crete, Thessaly, and Peloponnese. The levels of lignocellulosic biomass in Greece are estimated to be 2,132,286 tonnes on an annual basis, values that are very close to the cases of other Mediterranean countries like Italy and Portugal. In respect to the total agricultural residues, Crete produces 1,959,124 tonnes/year and Thessaly produces 1,759,457 tonnes/year. The most significant streams are identified to be olive pits, olive pruning, and cotton ginning remnants, with more than 100,000 tonnes/year each. In the latter part of this manuscript, a case study is presented for the development of a CHP gasification facility in Messenia. The biomass energy potential of the area is very promising, with about 3,800,000 GJ/year. The proposed small-scale gasification technology is expected to utilize 7956 tonnes of biomass per year and to produce 6630 MWh of electricity and 8580 MWh of thermal energy.

Keywords: lignocellulosic biomass; data analysis; energy potential; biomass characteristics; gasification; CHP

1. Introduction

RES (renewable energy sources), or new sources of energy, or green energy are forms of exploitable energy derived from various physical processes. The main purpose of RES is to limit greenhouse gas emissions, diversify energy supply, and reduce dependence on unreliable and volatile fossil fuel markets, especially oil and gas [1]. Utilization of biomass (thermal or biological processes) is also a RES, which contributes to the success of EU environmental and energy goals. Biomass is the biodegradable fraction of products, wastes, and residues of biological origin from agriculture (including plant and livestock), forestry, and related industries, including fisheries and aqua culture, as well as the biodegradable fraction of industrial waste and household waste. When biomass is burned to produce energy, it does not burden the atmosphere with CO_2 because it has already absorbed about the same or more of its CO_2 during its lifecycle [2].

The EU has a leading position in renewable energy technologies, with 40% of world patents in the sector belong to it. In 2012, almost half (44%) of the global renewable electricity potential (excluding hydropower) corresponded to the EU. The fact that the EU produces three times more electricity from RES per capita than any other part of the world is significant and each year exports energy from

RES worth € 35 billion [3]. The main triggers for these remarkable results and inclusion of biomass utilization were at the beginning of Directive 2001/77/EC [4]. The Directive states that the promotion of electricity produced from RES is a high priority for the community. The Biomass Action Plan (COM 2005/628/7-12-2005) [5] and the Directive 2009/28/EC [6], further highlight the need to establish national action plans for RES with a note about the different uses of the biomass. In 2010 a report was published about the sustainability requirements of a system using solid and gaseous biomass sources in electricity.

Presently, the share of RES for energy consumption in countries in the EU economic zone is very encouraging, with almost all countries to be at a percentage of 20–30%, with Iceland, Denmark, and Norway in the lead with RES participation reaching 50% [7]. Regarding the renewable energy technologies used in the EU, 40% of the generated green energy comes from the wood and another 20% from hydropower. Much of the exploitation of the wood goes to heating [8]. For 2020, the binding target of 20% of final energy consumption is to be derived from RES. To achieve this, EU countries are committed to achieving their own national target ranging from 10% for Malta to 49% in Sweden. They are also required to cover 10% of transport fuel using RES [9,10].

Primary production of RES in the EU-28 in 2014 was a 196 million tonne of oil equivalent (TOE), a share to the order of 25.4% of total primary energy production from all sources. The most important source was solid biofuels and waste recovery, accounting for two-thirds (63.1%) of primary RES production in 2014. Hydroelectric power was the second most important factor in RES (16.5% of the total) followed by wind energy (11.1%). Although their production levels remained relatively low, there was a rapid expansion of wind and solar power to a share of 6.1% of RES produced in 2014, while geothermal energy accounted for 3.2% of the total. Other types of RES, with very low rates, such as wave and ocean energy, are mainly found in France and the United Kingdom [11–13]. The prospects of development of RES are very high in Greece due to the climatic and geomorphological characteristics that allow for the high energy and economic efficiency of the projects. Significant progress has been made since 2010 when Greek Parliament implemented the Directive 2001/77/EC to the Greek Constitution [14]. In the total RES power installed, the share of biomass is very small as shown in Figure 1, with the main reasons being the complex institutional framework and the negative reactions of the local community [15–18].

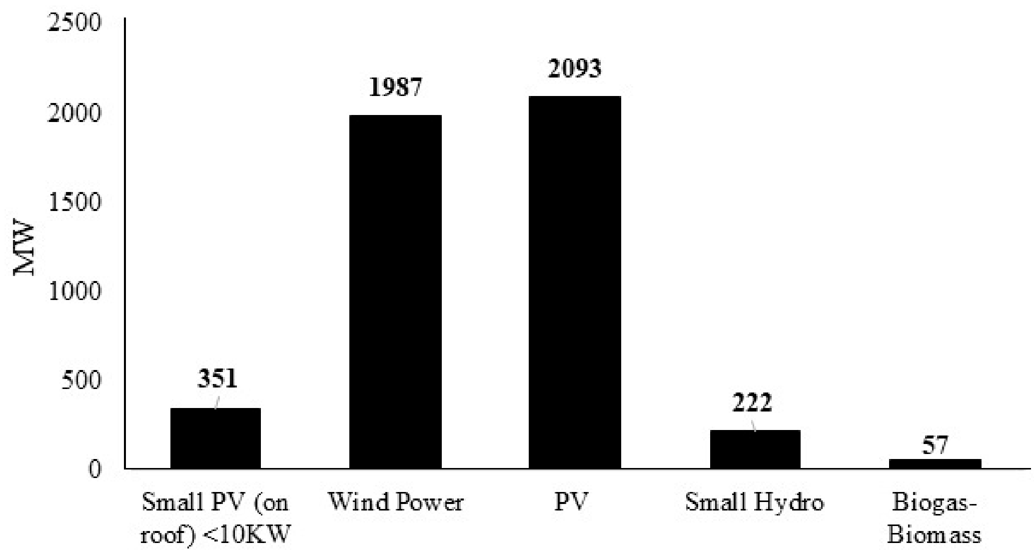

Figure 1. Installed RES (renewable energy sources) in Greece, October 2016 [7].

The use of biomass for electricity generation is interesting as it is RES, but it is limited by the cascade principle, which is a key EU strategy [19]. The principle of the sequence suggests that biomass should be used in the following order of priority: Reuse, recycling, bio-energy, and disposal.

The rationale behind the principle of sequencing is that the life cycle of biomass needs to be maximized in order to ensure the viability of the bio-economy, but also to bring some balance to the market due to subsidies in the field of bioenergy [20]. Therefore, the exploration of biomass sources that do not "break" the principle of the sequence and which (currently) are not used is a matter of great interest. Rural waste/agricultural waste is in compliance with these criteria and further study on the possibilities of exploiting this resource is a matter of high concern [21,22]. The usual methods of calculating agricultural waste are usually calculated indirectly and in relation to expected yields and sustainable harvesting levels of known agricultural crops. For this reason, we observe a relatively wide range of estimates between the different studies of their annual production at EU level. The lowest estimate is 0.73 EJ/y and the highest is 1.43 EJ/y [23–25]. The very small participation of biomass in the Greek energy balance is the main purpose of the research.

While most European countries classify the energy use of biomass as a major source of electricity and thermal energy [26], Greece disposes it in the environment uncontrollably or in landfills, while farmers usually proceed with the burning of residual biomass in their fields [27]. Both solutions have a great risk of ecological disaster. For the present study, the attempt to investigate this phenomenon, began from an analysis of the main points of the community and national institutional framework for the exploitation of biomass and despite the existence of numerous community directives, Greek laws, and ministerial decisions. However, with considerable investment interest, almost the total number of projects remained at the licensing stage. Another reason may be the ignorance of the actual available biomass potential and its energy content as well as reactions to renewable energy projects using biomass, which is commonly referred to as "Not in My Back Yard" [28]. Therefore, the focus of this study has been the assessment of biomass potential in Greece and a state-of-the-art energy valorization case study. Biomass gasification has the advantage of high electrical efficiency in small-scale operations and provides a distinct advantage in comparison to conventional biomass combustion technologies [29–31]. The high efficiency, along with the extended commercial applications in Europe, have led us to consider gasification as the best-case scenario for energy valorization of biomass.

The success of South Tyrol in biomass valorization can be replicated in many regions in Greece with satisfactory biomass qualities and the ability to develop small biomass projects. The fact that they have similar geomorphological characteristics, 48% of South Tyrol is covered by forests and only 50–60% of natural forest growth is used, with most stocks at high altitudes (78% above heights of 1.2 km), strengthens this point of view. The Italian Energy Regulatory Authority set high tariffs for the sale of energy generated in the public grid and, with other measures, have put out incentives to develop small-scale applications that are more cost-effective than large-scale ones [29–31]. There is a high concentration of technologies smaller than 200 kW_e and some of them are deliberately smaller than 50 kW_e. This "GAST" project (Gasification in South-Tyrol: energy and environmental assessment) includes a large number of small-scale Combined Heat and Power (CHP) plants based on biomass gasification and aims to monitor and evaluate some representative gasification units and to understand the use of gasification technology [32–36].

Although Greece is not characterized by significant agricultural and livestock production, in the present work, an attempt has been made to calculate both the total biomass potential for the lignocellulose sources on a national level and for the respective administrative regions. The results have been very encouraging, proportionally of course, with the size of the country and with correlation with its energy consumption. Depending on these numbers, the most suitable method for combustion of biomass and energy production, which is proven reliable and has been extensively used for transportation and farming systems, is gasification. The technical features of some of the proven gasification technologies in Europe that have the specifications to be used in small and medium scale projects in Greece are presented, including Urbas, Pyrox, Ankur, Spanner, Burkhardt, Mothermik, and Kuntschar.

2. Materials and Methods

The national targets, according to the National Waste Management Plan, are set for two management alternatives. On the one hand is the utilization as a source of organic substance for the production of soil improvers. On the other hand is energy recovery, either as a biofuel or for energy production. According to the National Waste Management Plan, each administrative region compiles and makes public an integrated waste management plan (PECA), which defines the general guidelines for its management and indicates the appropriate measures to promote hierarchical and combined (a) prevention, (b) reuse, (c) recycling, (d) other recovery, such as energy recovery, and (e) safe final disposal at the regional level [37].

The last one includes mainly pruning and forestry products in general, since they are similar in composition, and other agricultural residues of plant origin, such as crop residues and withdrawn fruit and vegetables. The collection of data to export the results of this work started from the study of the thirteen Regional Solid Waste Management Plans, one for each Greek region. This study gave us information about the daily and yearly quantities (in kg) of tree crops, vineyards, agricultural crops, wasted fruit and vegetables, residues of the processing of two-phase oil mills, wine waste, straw, firewood (agricultural content), firewood (forestry), pruning of trees and shrubs, forestry remains, and leaves/branches (crops of tobacco, corn). Especially for olive oil residues (olive oil production), the quantities are adequate even for medium scale exploitation for gasification, due to massive production in southern Greece (Peloponnese).

For a more accurate export of results, we needed as up-to-date as possible data for each region, something possible through the collection of Strategic Environmental Impact Assessments (SEA) (which regions were available) which update the above-mentioned data of agricultural waste.

The re-review of the PECA results comes from the need to comply with all institutional developments at the European and national levels, the need to evaluate the implementation of the envisaged projects and actions so far, and to formulate proposals to achieve both the existing and the new waste management objectives. Thereafter, the next objective was to collect data on the distribution of the utilized agricultural area of holdings by basic use categories, by region and county. The source was the Hellenic Statistical Authority (HSA) through its Structure Survey of Agricultural and Livestock Holdings of the year 2013. The mission of the Hellenic Statistical Authority is to produce useful and relevant statistics for public policy, economy, and other areas of life. From all of the data, we used those that covered all holdings and their areas for tree crops and olives, whose residual biomass can be used, due to its special biochemical features, in biomass gasification combustion plants.

The most difficult part in the collection of biomass data was the calculation of biomass potential from solid residues due to many available sources not distributed according to the work plan. For each administrative region we presented the biomass potential (in tonnes) of the year 2010, as well as the available biomass energy from the corresponding quantities (in GJ) from point biomass sources, arable crops, greenhouses tree plantations, vineyards, and forests. The main source of these raw data was the annual agricultural statistics of the Hellenic Statistical Authority (HSA) and Geodata, which is a webspace with open geospatial data and services for Greece, forming a national catalog of open data. These data needed to be processed in order to be summarized from the municipality to the administrative region level. The results were crosschecked by sources from the Center for Renewable Energy Sources and the National Agency for the Promotion of Renewable Sources. From the work of other researchers in specific regions, such as Western Macedonia, we collected data from other specific biomass sources, such as wheat (hard), other cereals, citrus fruits, peaches, pears, cherries, legumes, corn, and vegetables [38].

At last, we tried to link the estimated amount of biomass produced per source of interest with the regional Gross Domestic Product (GDP). We noticed that in the regions with the highest biomass potential, the total participation of the primary sector in its economy was at a high level. To extract this conclusion, we studied the Operational Program of each region from the years 2015–2019, which is also another way of confirming the correctness of the results.

3. Results

3.1. Greece—National Level

The term "agricultural and livestock waste" means any kind of by-products or derivatives of agricultural and livestock farming which either have ceased to have any economic value for the enterprise or their further management or processing is considered to be economically unprofitable. In such a case, these are considered to be "useless" for the activity that produces them and are intended to be removed, either in solid or liquid form [39]. Agro-livestock waste includes the following: Livestock waste, crop residues, fresh fruits and vegetables, greenhouse coverage plastics, fertilizer, agrochemical and pharmaceutical packaging waste, irrigation equipment withdrawn, and parts of agricultural machinery [40,41].

In order to meet the needs of electricity, heating and cooling, and transport targets for installed power and output the energy production from biomass was set in line with EU Directive 2009/28/EC. The estimations of total non-hazardous agricultural and livestock production from 2011 and the forecast amounts for 2020 are shown in Figure 2.

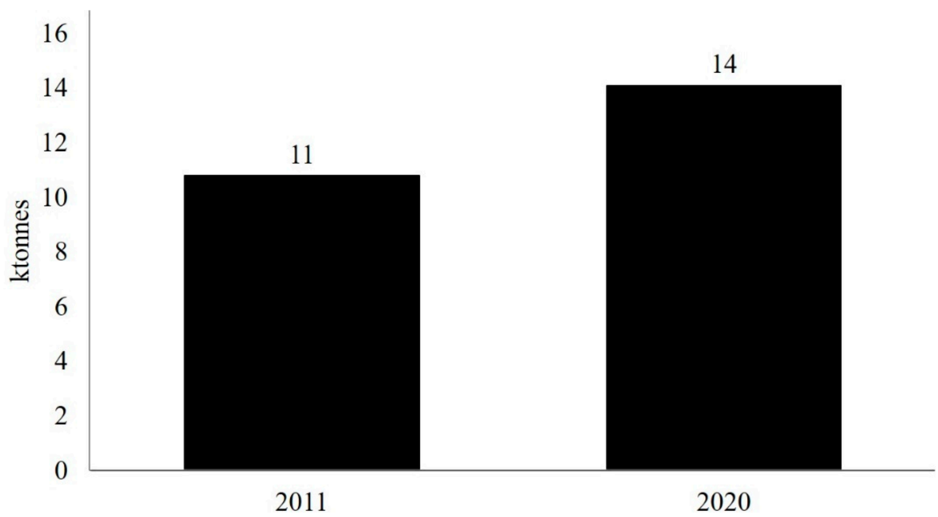

Figure 2. Estimation of non-hazardous agricultural and livestock production in Greece.

According to estimates by the Ministry of Development (2007), the energy equivalent of the agricultural and forest residues available annually is estimated at 1,000,000 tonnes, while other estimates show that the total available biomass in Greece is about 7,500,000 tonnes of residues of agricultural crops and 2,700,000 tonnes of forest logging residues [42–44]. The distribution of annual biomass production, in tonnes, by agricultural waste category in Greece is shown in Figure 3.

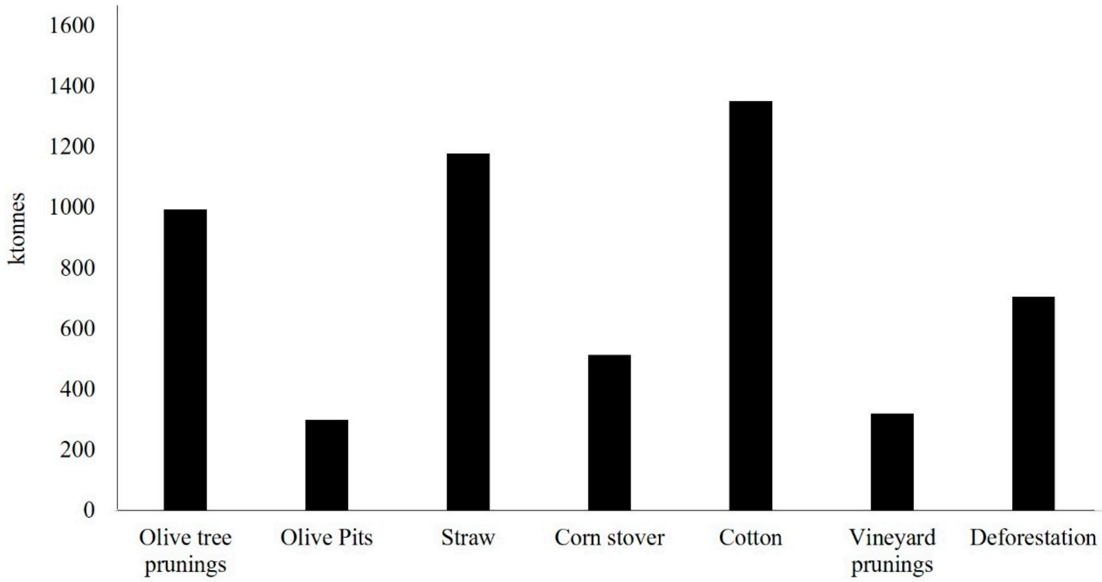

Figure 3. Distribution of annual biomass production, in tonnes, by agricultural waste category in Greece [15].

In Figures 4 and 5, the annual quantities of biomass, per source and region, are shown. Specifically, Figure 4 shows the annual quantities of biomass per source in the Greek territory. The arable crops are in first place, with tree plantations in second with about 1 million tonnes of annual biomass production. However, if we focus on the amount of lignocellulosic biomass (tree plantations, vineyards, and forests), it is estimated at about 2,132,286 tonnes at an annual basis [45–47].

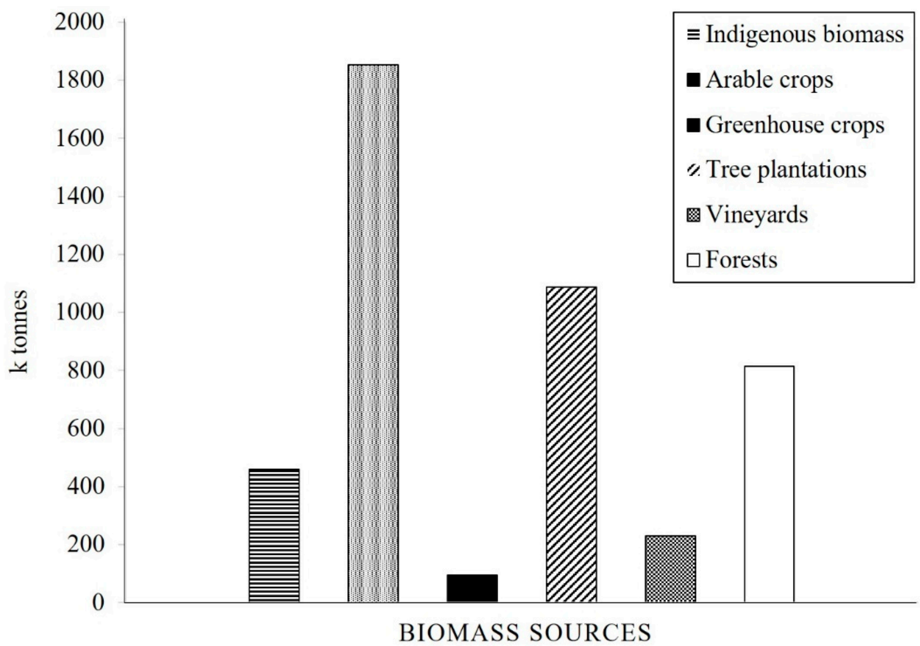

Figure 4. Annual quantities of biomass per source in Greece [16].

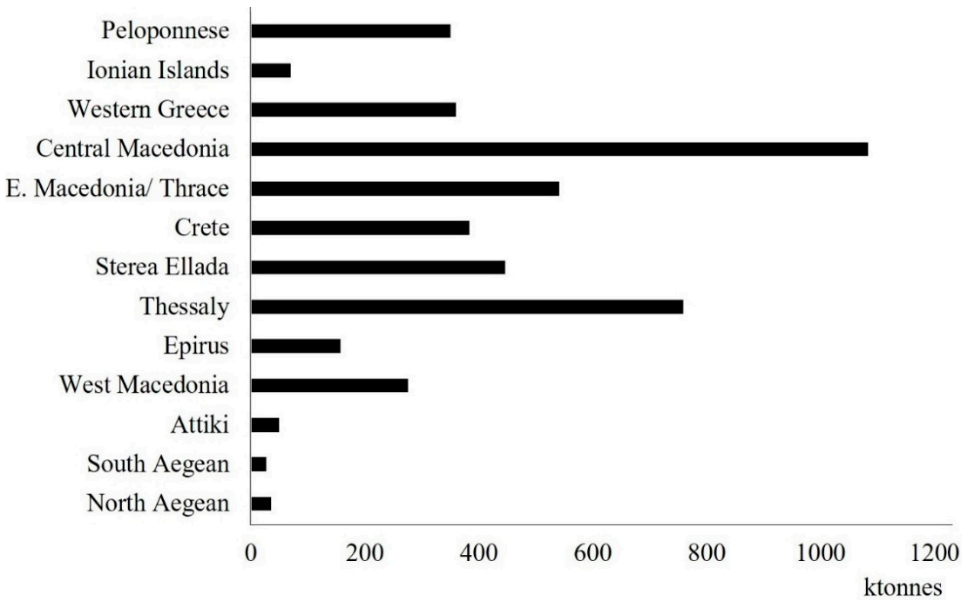

Figure 5. Potential of woody biomass in Greece by administrative region (ktonnes) [16].

Subsequently, Figure 5 presents the total woody biomass by region, while Figure 6 shows a more specific the total biomass from tree plantations and forests per administrative region. From these figures, we see that the first in production of woody biomass is the region of Central Macedonia with 1,083,272 tonnes per year, followed by Thessaly with 759,654 tonnes, and East Macedonia &Thrace with 54,792 tonnes. For the quantities of biomass from tree crops and forests, Central Macedonia is again the first, producing 463,849 tonnes, followed by Crete with 234,741, and Peloponnese with 219,595 annual tonnes [48].

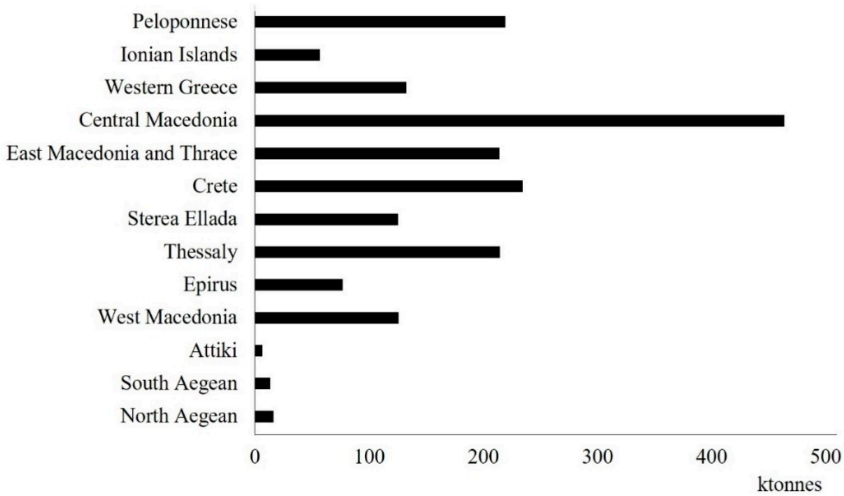

Figure 6. Potential of woody biomass (tree plantations and forests) in Greece by administrative region (ktonnes) [16].

In addition to the calculation of biomass potential, an important role in its use for energy production is fulfilling its biochemical characteristics, such us density, ash content, moisture content, volatile solids, alkali metals, and calorific value. Values that are more crucial are ash content, calorific value, and moisture content. The melting and re-aggregation of ash causes problems (obstructions, deposits, and operating difficulties in the fluidized beds). Ash content in some elements, such as K, Na, and Si may cause major problems and also damage to a biomass utilization equipment. Melts are deposited in the burner, boiler, gasifier, heat exchanger, and exhaust purification systems [49,50].

The calorific value of most types of biomass ranges from 17–20 MJ/Kg but the assessment of a biomass source should not be based solely on the calorific value but also on the ease of transport, treatment, storage, and safety of its use [51]. It is very important in the energy conversion of biomass, whether it is thermochemical conversion or biochemical. It is true that an increase in humidity from 0 to 40% reduces its calorific value by 66% [51]. In some farm residues, such as straw and shells, moisture can be less than 10%, wood has an average moisture content between 40% and 50%, while biomass from animal waste generally has a very high humidity. Biochemical processes (anaerobic digestion) require materials with high moisture content, unlike thermochemical processes (combustion), where high humidity has a negative effect on their energy efficiency [52]. Table 1 below shows the main qualitative features of biomass sources that we may encounter in Greece.

Table 1. Mean values of qualitative characteristics of known biomass sources (calorific value, humidity, ash) [53–58].

Types of Biomass	Net Calorific Value (MJ/Kg)	Moisture Percentage (%)	Ash Content (%)
Corn	14	15	4.5
Switch grass	17.4	50	4
Straw of common wheat	18.8	6.66	3.22
Straw of durum wheat	18.5	6.57	3.98
Cotton	15	15	6
Olive Core	19.02	6.86	5.17
Eucalyptus	19	9	2
Sugar cane	8	50	2.5
Coffee	16	10	0.6
Pear pruning	20.6	7.84	3.71
Apricot pruning	20.5	8.35	4.89
Olives pruning	14.85	13.83	1.92
Cotton ginning remnants	14.6	13	16
Rice	14	9	19
Tree trunks	7.5	10.9	2.05
Nuts' shells	18.8	8.34	2.6

3.2. Greece—Regional Level

At the regional level, we chose to present the biomass potential of the region of Thessaly and Crete and a case study of an installation of a gasification unit in Messenia of Peloponnese, with different reasons for each case. Thessaly, due to the considerable quantities available and Crete both for the quantities and for the different types of biomass that we encountered during the study. In addition, Crete, due to its geomorphology and insularity, a single biomass collection system can be designed more easily, with cooperation of locals and farmers and then to be exploited in a gasification unit. The electrical and thermal energy could be used for the needs of the island of Crete.

The regional unit Messenia, of the administrative region of Peloponnese, has a large amount of pruning's from olive trees and a problem with proper environmental and energy management. Therefore, the case study of the gasification unit shows a way for the best exploitation of them. Although the unit is small scale, it could be a good example for more projects like this and, finally, may be a part of a larger energy production and waste management system.

3.2.1. Administrative Region of Crete

Crete is the largest island in Greece and the second largest in the Eastern Mediterranean, after Cyprus. Its area is 8336 km^2, with a population of 623,065 inhabitants, and about 160 km southern of the Greek mainland [59]. Due to its particular climate and geomorphology, it exhibits a variety of activities in almost all sectors of the economy. The source of origin of agricultural waste is agricultural activities by agricultural cooperatives and individual farmers. The waste mainly includes pruning and food processing residues (mainly cheese and olive oil).

The produced livestock waste mainly concerns the rearing of cattle, pigs, sheep and goats, but is characterized by a high organic load and a high content of nutrients, such as nitrogen, phosphorus, and potassium. Planting crops and vineyards are of particular interest, from where significant amounts of deciduous crops are produced, with the PECA giving direction for their rational disposal in the future [42]. Tables 2 and 3 show the total prunings per crop, per regional unit, as well as the farms on the island that are of interest as potential sources of woody biomass.

Table 2. Annual quantities of pruning products, Regional Unit of Crete [59].

Types of Biomass	tonnes/year
Tree crops	14,647
Vineyards	44,800
Agricultural crops	59,447
Total	118,894

Table 3. Agricultural holdings in the region of Crete (land in thousands of acres) [60–62].

Area	Total Trees		Olive Trees		Trees Except Olive Trees	
Sub Regions	Tree Crops	Areas	Tree Crops	Areas	Tree Crops	Areas
Iraklion	41,409	691	41,236	680	3777	11
Lasithi	12,344	195	12,341	192	1987	3
Rethymno	12,520	253	12,489	241	2449	12
Chania	20,165	334	19,622	302	5266	32
Total	86,439	1474	85,688	1416	13,479	57

Of particular interest is olive mill waste, due to the large quantity of olive oil production on the island. The main part of the biomass is a byproduct of the primary processing of olives. The estimation of the residual biomass of the mills is based on the view that the two-stage mills, in the near future, will eliminate those with three phases. The main type of waste is olive oil, containing the olive-pomace and the rest of the plant walnuts. Three-phase oil mills can be completely absent of liquid waste but are characterized by a high moisture content (62–65%). Table 4 shows the estimated quantities of solid waste from the two-phase oil mills per peripheral unit of Crete [43,44].

Table 4. Quantities of bi-phase oil mills [59].

Regional Unit	tonnes/year
Iraklion	261,234
Lasithi	78,200
Rethymno	25,880
Chania	130,262
Total	495,576

Figure 7 presents the biomass potential by biomass source and regional unit of Crete, where the regional unit of Iraklion has serious amounts of biomass products coming from tree plantations and greenhouses. Lasithi comes in second place in the same biomass categories.

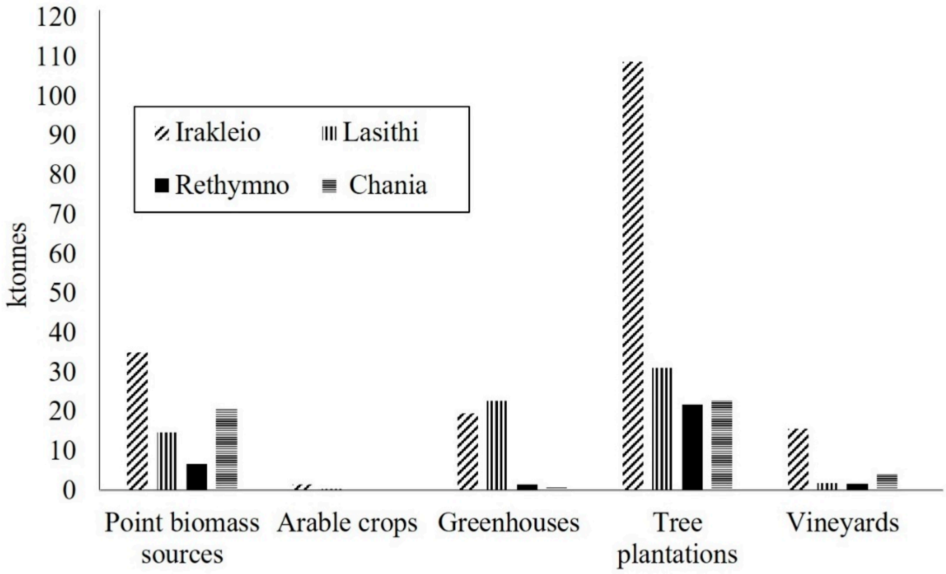

Figure 7. Biomass potential by source and Regional Unit of Crete (in ktonnes) [16,21,22].

The values for the available energy from the biomass exploitation are presented in Figure 7. The available energy for the first biomass source in quantities (tree plantations) can reach 1,950,124 GJ per year, as shown in Figure 8.

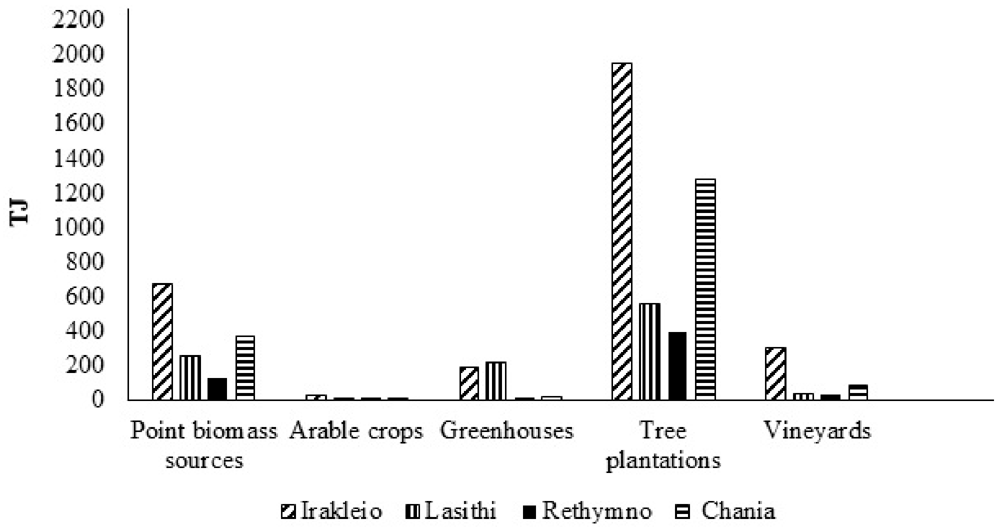

Figure 8. Available biomass energy by source and regional unit of Crete (in TJ) [16,21,22].

In Figure 9, we calculate the annual tonnes of biomass potential from all biomass sources, with tree plantations in first place with 234,741, followed by point biomass sources, with 77,607 annual tonnes of productivity.

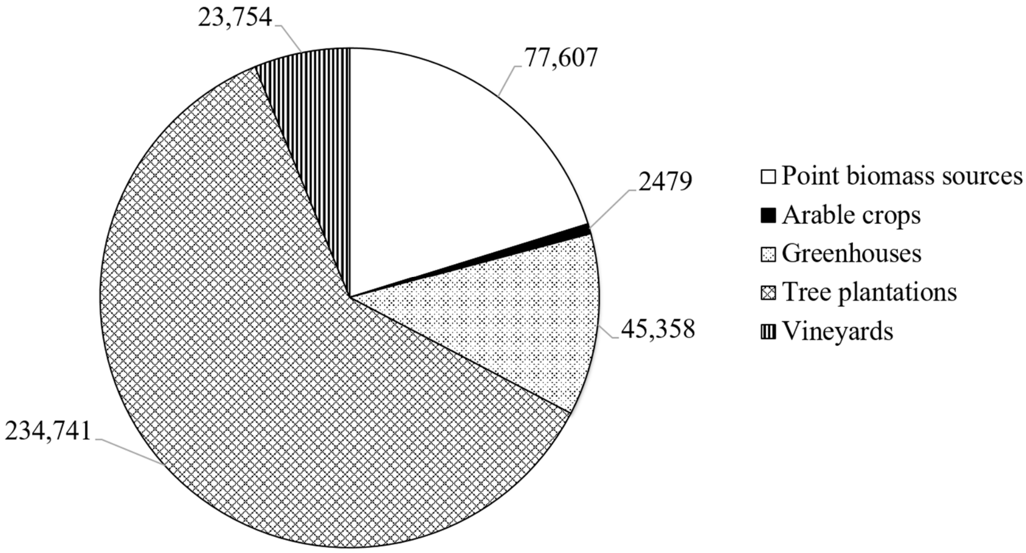

Figure 9. Total Biomass potential in the Region of Crete (in tonnes) by biomass source, 2010 [16].

3.2.2. Administrative Region of Thessaly

Thessaly is a region in central Greece with a total area of 14,036 km^2 and a population of 732,762 inhabitants. Its capital is Larissa and the ground, in terms of its formation, is 50% mountainous and semi-mountainous and 50% flat and includes the plain of Thessaly, which is the largest in the country and a major granary [63]. The region of Thessaly, with a variety of agricultural activities, is ranked among the areas with high biomass potential. The latter include mainly pruning and forestry products in general, since they are similar in composition, and other agricultural residues of plant origin, such as crop residues and withdrawn fruit and vegetables. The PECA of Thessaly aims to exploit agricultural waste and forestry waste through the production of energy and its co-treatment with other types of waste. For their management and utilization, they summarize the following: Creation of a Green Point Network to help citizens with screening all waste streams at the source, biological treatment plants (composting and/or anaerobic digestion), and low moisture biomass processing plants for the production of standard pellets. An important parameter is that, with regard to the burning of residues properly, very strict restrictions are set [64,65]. Tables 5 and 6 summarize the quantities of recoverable biomass and the number of tree farms in each region.

Table 5. Quantities of recoverable biomass in the regional unit of Thessaly [65,66].

Types of Biomass	tonnes/year
Agricultural residues	1,759,457
Dry agricultural residues	523,197
Final agricultural residues	299,197
Livestock residues	1,286,799
Total	3,868,650

Table 6. Agricultural holdings in the region of Thessaly (land in thousands of acres) [61].

Area	Total Trees		Olive Trees		Trees Except Olive Trees	
Sub Region	Tree Crops	Areas	Tree Crops	Areas	Tree Crops	Areas
Karditsa	576	5	356	2	240	3
Larisa	8461	168	5338	63	4788	105
Magnesia	12,050	243	10,780	196	3556	47
Trikala	2539	17	1726	10	905	7
Total	23,626	433	18,200	271	9489	163

Figure 10 presents the biomass potential by biomass source in the regional unit of Thessaly. In the region of Larisa there is a remarkable biomass potential of arable crops, followed by the regional unit of Karditsa [66]. These results come from the huge agricultural activity in the area.

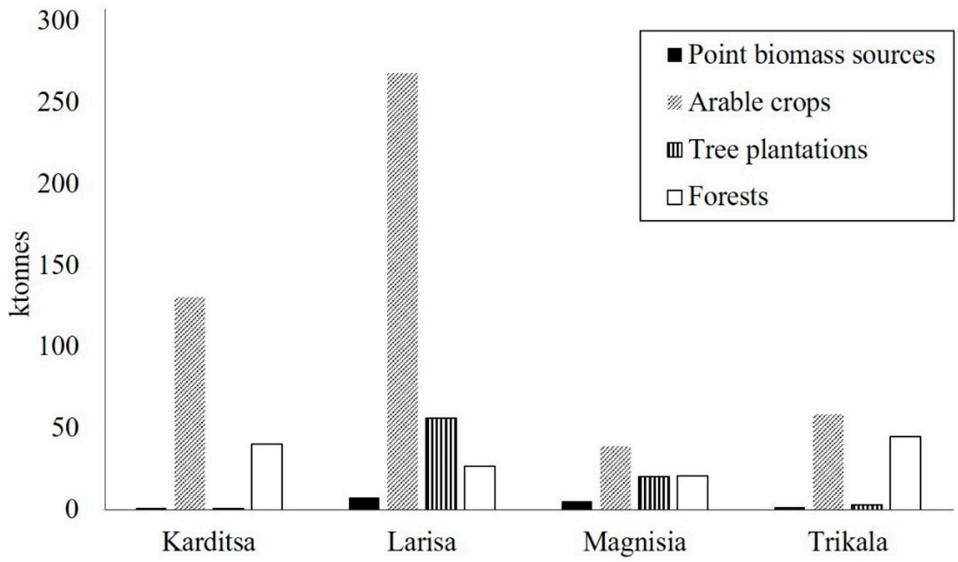

Figure 10. Biomass potential by source and Regional Unit of Thessaly (in ktonnes) [16,21,22].

Figure 11 presents the corresponding figures for the available energy from the biomass exploitation. The potential energy of arable crops exploitation can reach 4,767,020 GJ per year.

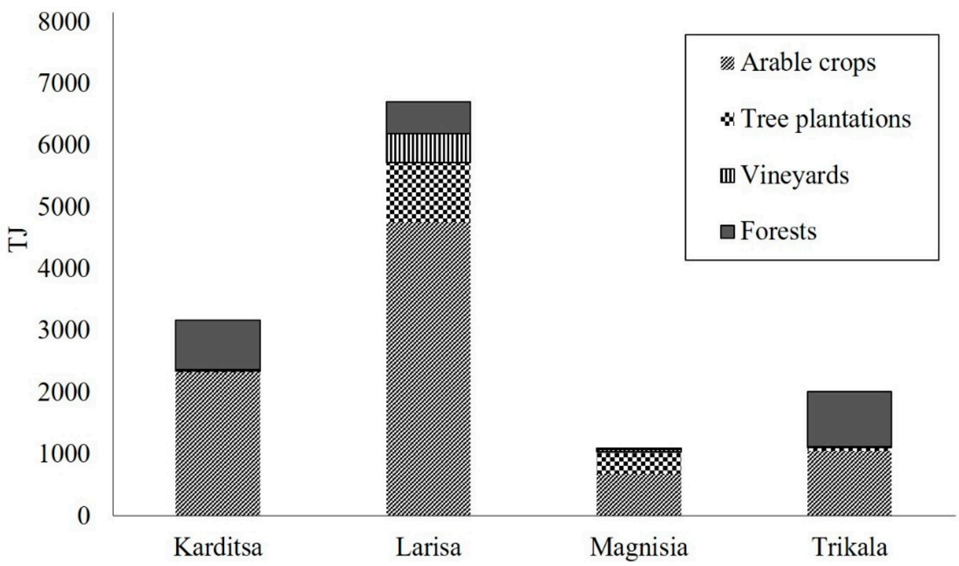

Figure 11. Available biomass energy by source and Regional Unit of Thessaly (in TJ), 2010 [16,21,22].

In Figure 12, we present the annual tonnes of biomass potential from all biomass sources. Arable crops are in the first place with 496,093 tonnes annually.

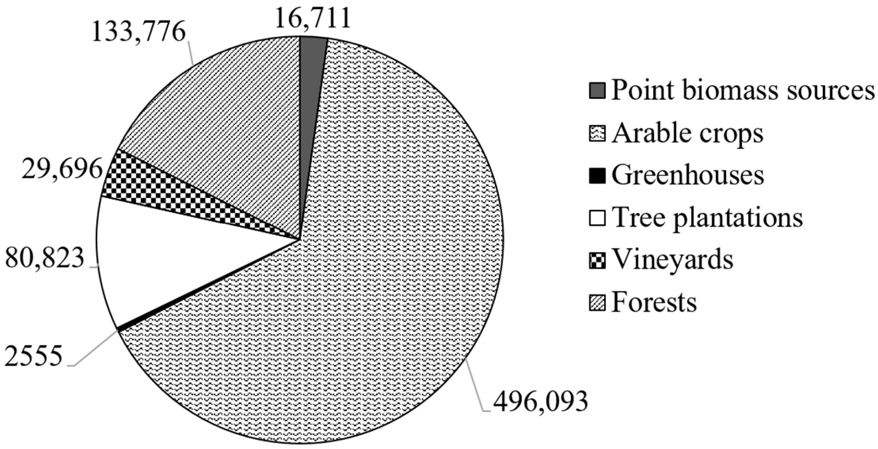

Figure 12. Total biomass potential in the region of Thessaly (in tonnes) by biomass source, 2010 [16,21,22].

3.2.3. Installation Potential of a Gasifier in Messenia

The potential of biomass in the area is at a very good level and is also an outcome of the agricultural land of the region, dominated by the tree crops at 62.6%, followed by the category of other land with 18.9%. An important part of the agricultural land of the region is also occupied by annual crops, with a percentage of 12.5% [67]. The dominant cultivation in the Peloponnese, and, in particular in the regional unit of Messenia, far from second place, is the olive tree. The number of olive trees in Messenia reaches about 16 million, with annual olive oil production exceeding 50,000 tonnes being the locomotive of growth in the region. In Figure 13 we see that biomass energy potential of tree plantations is about 3,800,000 GJ, most of it to be from olive trees [68].

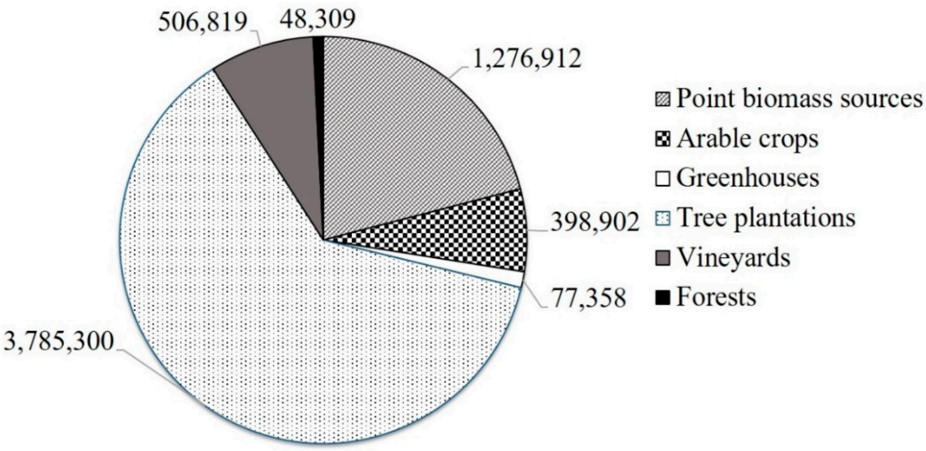

Figure 13. Total biomass energy potential in the Region of Peloponnese (in tonnes) by biomass source, 2010 [16,21,22].

The natural consequence of the cultivation of the olive tree is the waste resulting from it, the most important in our field of study, which is biomass, the decay waste. A large amount of the daily produced mass remains untapped and causes significant local pollution to the environment, since no restrictions exist and no law requires it to be processed [69].

Table 7 shows the estimated annual quantities of pruning for both olives and other tree crops and two-phase oil mills in the regional unit of Messenia, part of which will be used as a raw material for the case study of the gasification unit.

Table 7. Quantities of agricultural waste (in tonnes/year, 2007) [69].

Regional Unit of Messenia—Cuttings Quantities (tonnes/year)					Pomace (tonnes/year)
Olives	**Vineyards**	**Orange**	**Mandarins**	**Lemons**	**Waste of Two-Phase Oil Mills**
382,589	14,324	3335	781	101	194,072

For the management of waste, including the agricultural ones, which come from the pruning, the objective for the Peloponnesian region is sustainable management (reuse, recycling, energy recovery, and safe disposal) with substantial private sector involvement in areas of business interest. In addition, where possible, the use of best available techniques takes into account technological applicability and economic viability [68,70].

In recent years, the need for further development of RES is emphasized through the exploitation of natural resources. About 8% of the total national electricity is produced in the Peloponnese region [71] with the contribution of thermoelectric and hydroelectric power stations in Megalopolis [72] and Ladona [73], with the first one burdening the environment in various ways, such as gas emissions, waste, and alteration of geomorphological characteristics. The principle of gradual decommissioning of fossil fuels has been given with the development of RES exclusively from wind and photovoltaic technologies, exploiting the region's rich wind and solar potential. The biomass has zero participation in this effort, which was incomplete anyway, due to the change of the institutional framework for RES at the national level [69,74]. The total installed power of photovoltaic stations is 297.4 MW, followed by wind power stations with 254 MW, and hydroelectric stations with 3.99 MW [75].

The proposed gasification technology is the Pyrox TYPE P850 CHP gasifier, which is characterized as a small-scale cogeneration unit starting from wood chips which, after thermo-chemical treatment, are converted into a combustible gas which, after having undergone the necessary cleaning and cooling, is fed into an internal combustion engine. It will utilize 7956 tonnes of biomass per year and will produce 6630 MWh of electricity and 8580 MWh of thermal energy with a total cost of € 4.3 million [76].

The raw material will be according to specifications (dry matter $\geq$ 60%, maximum moisture content 40%, and normal particle size 20–100 mm > 90%). The annual heat consumption is 4773.6 MWh for the annual 7956 tonnes of the raw material of the plant, as long as the drying system requires 10% reduction in humidity, 0.6 kWh/kg (2.16 MJ/kg). The remaining cogenerated thermal energy will be utilized in other functions to minimize its discharge into the environment as much as possible, for example in greenhouse crops. As for the residual ash of combustion, it will be collected from the bottom of the bed, removed by means of a transport screw, and stored. In addition to the inorganic components, unburnt coal remains at about 10–20% of the total ash weight [77].

The raw material to be used is deciduous olive residue remnants in the vicinity. The plant will be supplied, at regular intervals, by trucks with the biomass as it is produced at the source, then stored in an appropriate place and subjected to chopping and drying at a rate proportional to the plant's needs. It is important to ensure that the raw material is of adequate quality and size, that its origins are known, and that any inappropriate pieces are sorted in a place before entering the shredder.

3.3. Rest of Europe

Funding of other studies in several European countries and regions can been seen comparatively with the results of Greece. Starting with Italy, a country in southern Europe, the estimated gross total of crop residues is 20,027,874 tonnes/year, of which around 67.4% are herbaceous residues, 28.2% arboreal ones, and 4.4% are the only two agro-industrial residues considered. The forest residues, coming from broad-leaf and resinous high trees and coppices (2,180,581 tonnes/year), have to be added to the gross amount so the grand total rises to 22,208,455 tonnes/year. The total final energy, which could be generated from the residual biomass, is equal to 191,336,760 GJ [78].

In Portugal, a country with similar characteristics to Greece, wood residues, animal waste, and municipal solid waste are the most common biomass resources available. Forest residues play an effective role to produce biomass energy forest residues (41,799,600 GJ/year) and the plan is to implement an energy balance of about 300 MW of biomass power (pellets, cogeneration, and cement) [79]. Turkey, another country on the Mediterranean Sea and a neighbor country to Greece, has a forest area which occupies about 27.1% of entire land area, of which 50% is productive. The first place biomass source, in annual productivity, is crops, with of 70,000,000 tonnes and an energy value of 837,360,000 GJ. Second is forest residues, with 20,000,000 tonnes and 226,087,200 GJ. In recent years, many attempts have been made to utilize biomass, such as wood, hazelnut shell, agricultural waste residues, waste paper and wheat straw, tea waste, and olive husk, for energy production [80].

In Alto Alentejo, a fairly mountainous Portuguese region, with an area of about 6.084 km^2, located in the eastern part of Portugal, the integrated results of this biomass generation are 44,000 dry tonnes/year and the converted energy potential is 158,000 GJ/year [81]. Another very interesting region is Andalusia, with a surface area of 87,268 km^2 and 18% of the population of Spain. There are 4.7 million agricultural hectares (57% of the territory), one third of these are olive groves, which are the main source of the residual biomass. The total biomass potential is 139,294,836 GJ and the one of olive trees 33,620,004 GJ, about 24% of the total [82].

In the Canary Islands the estimated biomass potential, especially from Canarian pine, is at about 230,274,000 GJ/year, which, added to the biomass from agricultural residues, could reach the figure of 628,020,000 GJ/year, approximately. There are no plants or major investments in the biomass energy sector [83].

Analyzing and comparing the data from current study and European ones, we see some similarity in results proportional to the sizes of the countries or individual regions studied, as well as some particular morphological characteristics. The total amount of available biomass in Greece is estimated at 7,500,000 tonnes/year, with 2,132,286 tonnes of them as lignocellulosic biomass (tree plantations, vineyards, and forests), in an annual basis, very close to the total number of Italy and Portugal. The big difference with Portugal, compared to Greece, is that the plan for the installed power of biomass utilization units is 350 MW while Greece is presently still searching for ways to overcome the complex institutional framework, social reactions, and a nearly hostile investment and tax environment.

On the other hand, Turkey seems to have the biggest amount of forest residues (ten times compared to Greece, Italy, and Spain) but, in its exploitation for electricity and heat production, remains at Greek levels. At this point, we have to mention that we assume that a big part of the lignocellulosic biomass of Greece and Turkey cannot be exploited at a reasonable cost.

The Portuguese region Alto Alentejo has many similarities to administrative region of Crete. The area of Alto Alentejo (6084 km^2) and Crete (8336 km^2) as well as the productive activities and biomass quantities (44,000 tonnes of Alto Alentejo and 60,000 of Crete) are in nearly absolute ratio. Although the Canary Islands are of the same size as the aforementioned areas, they have nearly 100 times greater biomass energy potential due to the high quality of the biomass source (Canarian pine). Finally, studying the results of Andalusia and Peloponnese, two regions with high olive productivity, we see that the former, with 4 times greater area than Peloponnese and with similar ratio of olive trees, has an energy potential of 33,620,004 GJ from this main biomass source, compared to the 4,000,000 GJ of Peloponnese.

4. Discussion

The present work aims to provide comprehensive data about the biomass potential in Greece and detailed information about the specific production for the different regions of the country. This unique and thorough study has the scope to set a baseline for future bioenergy endeavors in Greece. The case study that is presented is an example that applies to lignocellulosic biomass. However, this manuscript also provides comprehensive information about other types of biomass that would require utilization of different technologies for energetic valorization. As an example, the waste fruits could be anaerobically digested for the production of biogas. The authors believe that this study can be used as a tool for the identification of such opportunities. Additionally, by providing data about all the available types of biomass, the current status of biomass potential in Greece is clear and straightforward. This can assist the policy makers to develop relevant legislation that can assist the development of regional solutions that will be optimized for the locally available biomass. This can reduce the costs and carbon footprint from the transportation of biomass.

5. Conclusions

The bulk of agricultural residues are discarded in landfills or burned uncontrollably onsite. In the framework of this study, the potential of agricultural biomass residues is presented. The results show that the available lignocellulosic biomass in Greece is estimated at about 2,132,286 tonnes on an annual basis. The most significant biomass streams are identified to be olive pits, olive pruning, and cotton ginning remnants, with more than 100,000 tonnes/year each. A case study of a gasification unit in the regional unit of Messenia is presented and highlights the interesting potential for investment in gasification technologies in the Messenian region. Messenia has an annual olive oil production that exceeds 50,000 tonnes. The vast amount of olives trees results in a biomass energy potential, from tree plantations, of about 3,800,000 GJ. The proposed gasification technology is expected to utilize 7956 tonnes of biomass per year and to produce 6630 MWh of electricity and 8580 MWh of thermal energy. In addition to raising agricultural income, creating new jobs, and increasing the green footprint at local level, a potential investment in gasification technologies can be a springboard for the Greater Peloponnese region to further exploit the enormous biomass potential and increase local and national development.

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