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Review

Current Status of Energy Production from Solid Biomass in Southern Italy

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Abstract: This work analyses and discusses data on thermochemical plants in Southern Italy that are fed with solid biomass. The analysis takes into account the biomass availability and potential together with the cost-benefit analysis using technology development and economic indicators (LCOE). A total of 63,762 units have been categorised according to the employed technology and produced energy: power plants for electricity production or cogeneration plants for combined heat and electricity production (53 plants) and thermal units for heat production (63,709 units). The eight regions of the area have noteworthy differences. In terms of electricity generated from solid biomass Calabria is by far the largest producer, followed by Apulia. Sicily, Sardinia and Molise provide lower amounts while Abruzzo, Basilicata and Campania generate almost negligible amounts. Regarding thermal production, Campania and Calabria are the largest producers, but Basilicata, Molise and Abruzzo generate the highest amount per capita. The area is far from fully exploiting its biomass potential, and there are also no district heating grids. Bioenergy can be remarkably competitive, provided that capital costs are relatively low and low-cost biomass is available, as it is the case of Italy. New applications and markets for sub-products (i.e., char, ash) would help in lowering the still not competitive economic indicators (LCOE).

Keywords: biomass-to-energy; circular economy; energy transition; renewable energy; Southern Italy

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1. Introduction

Promoting renewable energy is a top priority in the policy agenda of the European Union (EU) [1]. The final aim is to reduce the greenhouse gas (GHG) emissions so as to fulfil the targets defined at the Paris Conference of Parties 21 (CoP21), and to decrease the dependence on fossil fuels imported from abroad in the 27 EU countries (EU27) [2]. According to the European Commission (EC), in 2017 almost 17.5% of the EU's gross energy consumption came from renewable sources [3]. The Directive 2018/2001 on the promotion of the use of energy from renewable sources (RED II) [4] has made obsolete the previous one (2009/28/EC [5]) and established a framework to meet a minimum target of 32% of renewable energy in the EU gross consumption by 2030.

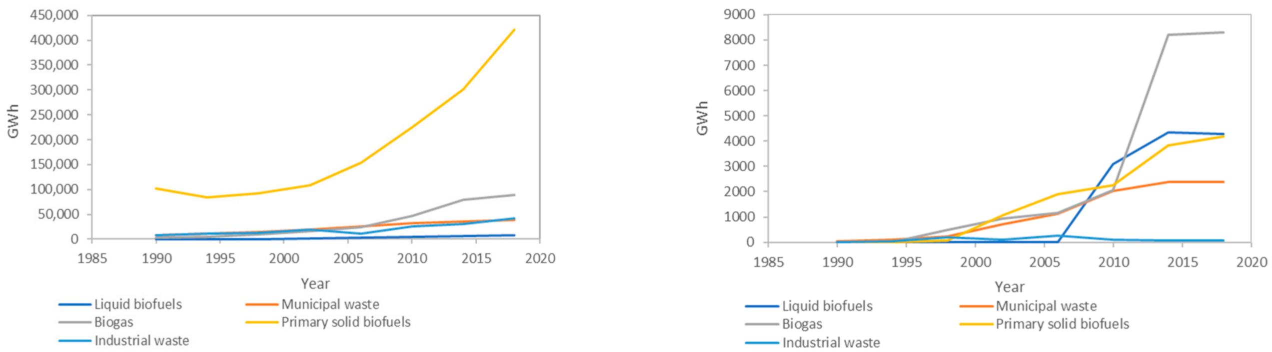
The renewable electricity capacity additions in Europe, in the period 2007–2021 are shown in Table 1 [6]. Remarkably, the International Energy Agency (IEA) forecasted a decline by 13% in 2020 compared with 2019, a 20% downward revision compared to what expected, due to the current sanitary emergency. This decrease is a direct consequence of lockdown measures, which delayed construction activity due to supply chain disruptions, social-distancing procedures, and financing challenges. Fortunately, some of the impacts from the COVID-19 pandemic are expected to be temporary and capacity additions are expected to rebound in 2021, possibly approaching the levels of 2019 [6].

Table 1. Trend of the renewable electricity capacity additions (in GW) in Europe (2007–2021). Based on IEA Renewable Electricity Capacity Additions, 2007–2021, Updated IEA Forecast. (2020), www.iea.org/statistics, All rights reserved [6].

2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
12.5	17	24.5	28.3	40.2	37.8	27.8	22.7	28.9	26.2	27.7	27.1	33.9	22.2	31.9

Renewable heat markets will also be impacted by the COVID-19 crisis, compromising the already slow expansion of renewables in heat production. Delays in the manufacturing, sale and installation of renewable heating equipment and the current low prices of oil and gas are hindering the cost-competitiveness of heat obtained from renewable sources. Also, planned investments in reducing fossil fuel heating are prone to be delayed or abandoned due to the lack of stronger policies, owing to the uncertain future financial situation.

Bioenergy is the main contributor in the distribution of renewable gross final energy consumption in EU27 [7]: solid biomass, biofuels, biogas and renewable municipal waste are currently more common in the heating and transport sector, whereas their contribution to electricity production is still less substantial. Bioenergy is less relevant for industrial purposes, although it has the potential to increase its contribution [8]. Bioenergy plays a relevant role in Italy, one of EU27′s main contributors. The electricity generation from biofuels and waste by source is shown in Figure 1a (worldwide) and Figure 1b (Italy). Primary solid biofuels are clearly the main contributors to the total share of the electricity generation worldwide whereas it ranks third in Italy, where biogas experimented a steep increase in 2010 to become the largest producer up to now. The gross heat production worldwide and in Italy by source of waste in 2018 [6] is shown in Table 2. Primary solid biofuels represent the main contribution in the renewable share with up to a 50% of the total produced heat.



(**a**) (**b**)

Figure 1. Electricity generation from biofuels and waste by source worldwide (**a**) and Italy (**b**).

Table 2. Gross heat production by waste source (2018) [6]. Based on IEA data from IEA (2020) Renewable electricity capacity additions, 2007–2021, updated IEA forecast, IEA (2020), www.iea.org/statistics, All rights reserved.

	Municipal Waste	Industrial Waste	Primary Solid Biofuels	Biogas	Liquid Biofuels
Gross heat production (worldwide), TJ	296,165	181,501	589,111	46,514	5683
Gross heat production (Italy), TJ	10,615	351	22,532	8952	2162

Among the different primary solid biofuels, solid biomass has a growing contribute to the Italian bioenergy landscape. Solid biomass can be converted into energy (thermal, electrical, or both) or useful materials through different technological solutions, depending on its properties and desired output. Nonetheless, due to its relatively low moisture content, it is often converted through thermochemical pathways, which can produce electricity and heat simultaneously. The gross production of electrical energy from biomass and waste sources has steadily increased until 2016, when it reached 19.378 TWh, against a total of 10.832 TWh in 2011 [6].

Although Italy has been a united country for more than 160 years, its regions still feature marked differences between one another, showcasing noteworthy disparities in economic and technological development and in the services provided to citizens. The most cited difference is perhaps that between northern and southern regions (the so-called "North-South divide"), with the latter underperforming according to several indicators [9]. The economic disparity between Italy's wealthy, industrialised northern regions and the agrarian, poorer southern regions is well known, with this gap still expanding. The historical origins of the gap involve many factors, including geographical differences, availability of natural resources and political choices. Southern Italy is generally considered to comprise eight regions: Abruzzo, Apulia, Basilicata, Calabria, Campania, Molise, Sardinia and Sicily. Although from a geographical point of view Abruzzo belongs to Central Italy, for statistical purposes it always is grouped with southern regions due to their strong historical and cultural bonds.

Despite the existing divide, southern regions do not perform poorly in terms of renewable energy. In a recent analysis focused on the use of public funds in Italian regions, Meleddu and Pulina [10] pointed out that Southern Italy regions are more efficient and produced more renewable energy than the national average. In terms of energy from solid biomass, southern regions show both positive and negative aspects; all of them produce it to different extents, but no district heating (DH) plants are present, in contrast with the highly developed technology located in the North [11]. This might be partially due to the cooler weather of the northern part in comparison with the milder weather of Mediterranean areas, where cooling demand is higher than heating applications. In general, DH plays a relatively marginal role in the Italian heat market with a supply to only 5% of citizens, against a European average of 12.4% [12]. In the national context, a potentiality of 37.6 TWh from waste through efficient district heating could be obtained.

In this perspective, the aim of this work is to characterise and analyse the current state of the art of energy generation from solid biomass through thermochemical technologies in the Italian southern area. We analysed the data on the availability of solid biomass in each region, and on the basis of that, we tried to understand how far each of them is to exploit its full potential. Moreover, the main plants are described. Through this review, data available in various Italian sources are collected and shown concisely in an international context, bringing them to the attention of the scientific and industrial communities.

The work is organised as follows: Section 2 describes the availability and potential of biomass in the area. Section 3 summarises the main conversion technologies and economic indicators. Section 4 discusses the energy and bioenergy situation the studied regions and describes the most representative plants. As a result, the dynamic databank started in our previous work [11] is updated by including the most representative power plants of the Southern Italy regions.

2. Solid Biomass and Its Distribution in Southern Italy

The European Commission provided the following definition of biomass: 'the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste' [13]. Biomass is clearly a wide category, comprising materials with various properties, shapes, and value. However, in all cases, it has a noteworthy advantage that is the non-fossil nature of its carbon. The combustion of biomass does generate CO_2, but its emission does not alter the natural carbon cycle, contrarily to fossil fuels. Compared to other kinds of renewable energy sources (solar, wind, hydroelectric), biomass has the advantage of being easily storable and allowing continuous operation, thus being much more unsensitive to climate conditions and posing less problems to the electricity grid. These aspects make biomass an attractive renewable energy source.

Despite these positive features, it is not true that exploiting biomass for energetic purposes is an entirely carbon-neutral activity. A biomass conversion plant requires to be built and supported by adequate infrastructure, and the biomass must be collected, pre-treated, and transported. Ideally these steps could be reduced and powered with renewable energy, but unfortunately this is not entirely feasible yet. Nonetheless, according to the RED II Directive [4], generating electricity or heat from woody biomass can avoid the 89 and 93%, respectively, of the emissions that would be caused by fossil fuels.

Regarding thermochemical conversion, biomass is most suitable for it when it has a low water content. The main type of biomass than can fulfil this requirement is lignocellulosic biomass, obtainable from wood and other plant parts (straw, shells, etc.). Forests and harvested fields are the main sources, providing biomass in the form of wood or agricultural residues. While the former has better properties and simplifies the plant design and operation, the latter is more likely to be a waste and thus more desirable in a circular economy perspective. Nowadays, 70% of the biomass employed for energy generation comes from forests [7].

This section summarises and comments the data on solid biomass availability in Southern Italy. The focus is put on the extent of the already available and partially unexploited biomass, originating from forest and agricultural activities. Biomass for bioenergy purposes can also be purposedly cultivated and several research outputs can support this practice [14–16]. Some crops appear to be particularly suitable, such as bamboo [16–19], which is suitable for the Italian climate, grows rapidly and has a good adaptability to degraded soil. Southern Italy is indeed more vulnerable to desertification than the rest of the country [20].

For the sake of simplicity, the data are only discussed on a regional scale, to infer the extent of the unexploited potential. When planning actual valorisation plants, other factors must be taken into account, such as the properties of the biomass and where it will be collected. The transportation range is of the utmost importance: if biomass has to be transported for more than 100 km, the environmental and energetic benefits become low or null. It is actually recommendable to plan the plant location on the basis of the supply chain, as Delivand et al. did for some Southern Italy regions [21]. It may often be better to create several small-scale plants than one large-scale plant, especially if the produced heat is to be employed for district heating.

2.1. Forest Biomass and Its Distribution in Southern Italy

Collecting wood from forest can be done without damaging the environment, provided that it is done according to sustainability criteria. These involve collecting an amount of wood lower than the amount that grows within the same period. Although several countries have specific regulations on the matter, Abbas et al. noted that general guidelines were still lacking in 2011 and further efforts were needed [22]. It is also important to stress that creating a virtuous woody biomass chain could provide several benefits to the often-neglected rural and internal areas of Italy, such as creating new jobs and infrastructure while lowering the cost for energy and avoiding domestic emissions [23]. Collecting low-value residual biomass can also hinder the spread of wildfires, pests and diseases, although the practice is still debated and its adequacy is probably site-specific [24]. A systematic review on this topic was recently provided by Santos and colleagues [25].

The European surface covered by forests is continuously increasing, contrary to what it is happening worldwide. More than 33% of the surface of Europe is covered by forest (2.27 million of km^2), with a 9% increase over the last 30 years [26]. This is another factor making forests a sustainable biomass source in Europe, although their special distribution is uneven [27]. In Italy, forests and woods cover $110{\cdot}10^3$ km^2, more than a third (36.5%) of the national territory [28] and in line with the EU average (40%). Nonetheless, Italy imports 80% of its wood demand from abroad and is one of the worst-performing EU countries in terms of energy generated from forest biomass [28]. Indeed, the latest Italian Report on the status of forests [29] states that Italian forests are largely underexploited, with the annual wood withdrawal being 71 m^3/km^2 against an European average of 239 m^3/km^2. The governmental organisation *Ricerca sul Sistema Energetico* (RSE, literally "Research on the Energetic System") estimated that a higher use of forest wood may increase the Italian electricity and heat production from 4 and 86 to 11.5 and 116 TWh, respectively [30], avoiding the emissions of nearly 8 million Mg of fossil CO_2 per year. A recent life cycle study conducted in Basilicata confirmed the positive aspects of a sustainable forest management [31]. The authors also pointed out that producing pellets from sawdust is less expensive than doing it from beech logs, and that the activities performed in the forest have the lowest environmental impact but the highest cost.

Southern Italy is in line with these considerations; Table 3 reports the distribution of forests among its regions. It can be noted that this coverage is only slightly lower than the national average (32.6% vs. 36.5%), but with a higher increase in the 2005–2015 decade (7.5% vs. 4.9%). Sardinia has both the largest forest surface and the highest percentage of forest coverage, which is consistent with its low population density. Only Sicily and Apulia have markedly lower percentages than the average; both are quite arid and have a lower mountain abundance than the national average.

Table 3. Distribution of forests in Southern Italy, 2015 projections [29] (the actual 2015 data are not available yet). Partially adapted from *INFC 2005–Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio. Ministero delle Politiche Agricole Alimentari e Forestali, Ispettorato Generale-Corpo Forestale dello Stato. Consiglio per la Ricerca e Sperimentazione in Agricoltura Unità di ricerca per il Monitoraggio e la Pianificazione Forestale (CRA-MPF)*.

Region	Forest Surface (km^2)	Forest Surface (%)	2005–2015 Increase (%)	Total Surface (km^2)
Abruzzo	4751	44.01	8.32	10,795
Apulia	1891	9.76	5.61	19,366
Basilicata	3939	39.41	10.50	9995
Calabria	6710	44.49	9.47	15,081
Campania	4869	35.83	9.36	13,590
Molise	1722	38.81	15.86	4438
Sardinia	12,414	51.53	2.32	24,090
Sicily	3816	14.85	12.86	25,703
Southern Italy	40,112	32.60	7.47	123,057
Italy	109,820	36.45	4.92	301,328

Compared to the rest of the country, Southern Italy has more public-owned forests (about 43%, against an Italian average of 33.5%). This can be a good aspect to plan their management, avoiding involving private owners. Nonetheless, several region have a high share of private-owned forests, as shown in Table 4 [29]. Abruzzo has the highest percentage of public-owned forests, possibly because it is the Italian region with the highest percentage of protected territory, hosting three national parks.

Other interesting data about Italian forests can be found in the latest national forest inventory (INFC [32], which stands for "Inventario nazionale delle foreste e dei serbatoi forestali di carbonio", i.e., National inventory of forests and of forest carbon sinks, available in Italian at www.sian.it/inventarioforestale/index.do), which is based on 2005 data (another one is in preparation employing 2015 data). The inventory proposes numerous further classifications for forests. Some of the provided data are the availability for wood withdrawal, the accessibility, the proximity to roads and the altitude gap from the road. The availability for wood withdrawal is based on the lack of restrictions (e.g., because of the existence of an integral reserve) and accessibility. Indeed, if a tree is too far from any kind of road or is placed at a significant height difference, it is unlikely to be successfully and/or economically harvestable. For this reason, we also gathered the data (Table 5) for the percentage of forests that is within 500 m of a road and within ±100 m of height difference (unfortunately, it is not possible to intersect the two data). The surface marked as "Available for wood withdrawal" may be overestimated from more practical points of view. On the other hand, these numbers are still large and, even with a very conservative approach, it may be safe to assume that roughly a third of the forest surface of every region can be exploited for wood collection.

Table 4. Forest ownership in Southern Italy, 2005 data [29]. Partially adapted from *INFC 2005–Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio. Ministero delle Politiche Agricole Alimentari e Forestali, Ispettorato Generale-Corpo Forestale dello Stato. Consiglio per la Ricerca e Sperimentazione in Agricoltura Unità di ricerca per il Monitoraggio e la Pianificazione Forestale (CRA-MPF).*

Region	Private Owner (%)	Public Owner (%)	Unclassified (%)
Abruzzo	42.74	57.17	0.09
Apulia	59.51	40.49	0.00
Basilicata	57.80	40.80	1.40
Calabria	54.22	45.50	0.29
Campania	60.44	39.56	0.00
Molise	64.14	35.12	0.74
Sardinia	64.66	34.50	0.83
Sicily	49.58	50.27	0.15
Southern Italy	56.41	43.05	0.55
Italy	66.19	33.47	0.34

Table 5. Accessibility of forests in Southern Italy, 2005 data [29]. Partially adapted from *INFC 2005–Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio. Ministero delle Politiche Agricole Alimentari e Forestali, Ispettorato Generale-Corpo Forestale dello Stato. Consiglio per la Ricerca e Sperimentazione in Agricoltura Unità di ricerca per il Monitoraggio e la Pianificazione Forestale (CRA-MPF).*

Region	Available for Wood Withdrawal (%)	Accessibility (%)	Distance from a Road within 500 m (%)	Height Gap from a Road within ± 100 m (%)
Abruzzo	73.43	91.07	54.81	51.12
Apulia	89.87	97.12	61.31	47.47
Basilicata	83.54	72.01	46.45	38.33
Calabria	70.52	73.30	51.11	50.49
Campania	70.60	80.25	46.92	44.92
Molise	89.89	94.22	81.53	72.47
Sardinia	78.87	89.74	67.49	54.10
Sicily	84.14	87.58	57.28	52.61
Southern Italy	77.76	84.71	58.19	50.83
Italy	81.31	87.48	54.92	51.32

As already stated, the sustainable amount of collected wood must be inferior to the wood increase, which differs from region to region. Obviously, this changes on a more local basis, but such detailed numbers are not available. On the other hand, the values for all the regions are in line with the Italian average, pointing out the good health of the forests and the availability of wood.

Table 6 summarises these data. The numbers are reassuring and prove that all Southern Italy regions have forests in perpetual growth. The yearly volume increase per surface area is lower than the national average for all regions (except Calabria and Campania), but the values are still remarkable and would translate in high amounts of wood that could be sustainably harvested.

Table 6. Volume and increase of forests in Southern Italy, 2005 data [29]. Partially adapted from *INFC 2005–Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio. Ministero delle Politiche Agricole Alimentari e Forestali, Ispettorato Generale-Corpo Forestale dello Stato. Consiglio per la Ricerca e Sperimentazione in Agricoltura Unità di ricerca per il Monitoraggio e la Pianificazione Forestale (CRA-MPF)*.

Region	Volume of Forest Wood (10^6 m^3)	Volume per Surface Area (m^3/km^2)	Yearly Volume Increase (m^3/y)	Yearly Volume Increase per Surface Area ($m^3/(km^2$ y))
Abruzzo	50.493	12,900	1,316,967	340
Apulia	12.160	8340	407,879	280
Basilicata	27.661	10,510	738,870	280
Calabria	87.967	18,790	2,524,411	540
Campania	42.503	11,060	1,566,083	410
Molise	14.636	11,040	422,162	320
Sardinia	32.883	5640	1,173,026	200
Sicily	23.183	9050	756,005	300
Southern Italy	291.486	10,519	8,905,403	325
Italy	1269.416	14,490	35,872,293	410

The actual amount of wood that can be obtained from the forests can be estimated from the previous numbers. We assumed that only 1/3 of the forest surface of each region can be employed for wood harvesting, that only 70% of the volumetric yearly increase is collected (in line with the European average [28]) and that the density of wood is 600 kg/m^3. The data are summarised in Table 7, together with a comparison with the numbers provided in a 2009 study by Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA) [33], focused on the energetic potential of biomass in Italy. The ENEA data are even more cautious than our estimates, because only 0.15 to 0.30 of the yearly increase is considered to be harvestable. Thus, the two values can be considered as possible boundaries of the actual value. It shall be noted that both the INFC data and the ENEA study are more than 10 years old. Nonetheless, since Italian forests are expanding, their use represents a conservative approach.

Table 7. Sustainably harvestable forest wood in Southern Italy (partially adapted from ENEA, www.enea.it).

Region	Estimated Harvestable Wood (t/y)	ENEA Data [33] (t/y)
Abruzzo	242,301	60,130
Apulia	79,422	46,430
Basilicata	165,438	65,280
Calabria	543,510	153,800
Campania	299,444	119,830
Molise	82,656	43,750
Sardinia	372,420	65,010
Sicily	171,720	25,580
Southern Italy	1,956,911	579,810
Italy	8,565,960	2,180,580

2.2. Agricultural Biomass and Its Distribution in Southern Italy

As previously stated, agriculture is another noteworthy source of residual biomass. Agricultural residues possibly constitute an even more desirable source of energy because they have a low-to-negative value, mostly no other application and do not need to be transported from remote areas where infrastructures may be lacking. Conversely, they generally feature a lower energy density and irregular properties and are thus less ideal for the functioning of common burners and gasifiers, although several technologies have been proposed to overcome these problems.

Agricultural residues are produced in large amounts and are currently vastly underexploited. According to the Food and Agriculture Organization of the United Nations (FAOSTAT), about 393 × 10^6 t of agricultural residues were burned on field in the world in 2017, generating considerable emissions and without providing any energetic advantage. Of these, 19.1 × 10^6 t were burned in the European Union and 1.50 × 10^6 t in Italy [34]. Agricultural waste is classified as 'special waste' in the Italian legislation, and its production in 2018 was 324,370 t [35]. This number clearly appears to be a large underestimation of the actual value. It probably only considers the amount that farmers pay to have disposed by a third entity, while they dispose of the majority themselves. A 2011 report by Isprambiente [36] indeed estimated a gross yearly production of 15.120 × 10^6 t of herbaceous residues, 3.585 × 10^6 t of pruning residues and 1.563 × 10^6 t of residual wood in Italy. These values seem to agree with those estimated in a 1997 study by Di Blasi et al. [37], with a yearly production of 14.5 × 10^6 t of agricultural residues, which could fulfil 7 to 10% of the electricity demand of that time. The most detailed study on this aspect to date is the already-cited 2009 work by ENEA, which provides the values for each region. These numbers are summarised in Table 8 for Southern Italy regions. Although the numbers are moderately dated, we do not expect them to have changed significantly.

Table 8. Production of agricultural residues in Southern Italy, 2009 data [33] (adapted from ENEA, www.enea.it).

Region	Herbaceous Residues (10^3 t)	Pruning Residues (10^3 t)	Pomace Residues (10^3 t)
Abruzzo	229.23	290.35	54.99
Apulia	1219.42	813.88	369.64
Basilicata	452.10	49.96	11.58
Calabria	212.11	1012.21	189.92
Campania	316.88	286.58	65.85
Molise	163.45	31.48	29.04
Sardinia	260.00	120.90	28.78
Sicily	731.97	597.92	186.35
Southern Italy	3585.16	3203.28	936.15
Italy	15,710.90	4906.40	1319.90

The data highlight that Southern Italy has a vast production of agricultural residues and generates the large majority of pruning and pomace residues of the whole country. These numbers further prove the potential of agricultural residues for energy production. While technological or logistic limits may make their exploitation unfeasible, even the proper handling of only a fraction of these amounts would bring enormous advantages to the Italian energy system and to the environment. As a matter of fact, Di Fraia et al. assessed the abundance of agro-industrial residues in the Campania region and stated that they could cover 14% of the region's heat demand [38], while Algieri et al. [39] affirmed that agricultural residues could satisfy the electric load of 178,000 families in Calabria.

3. Technology Development and Economic Indicators (LCOE)

Biological and thermochemical technologies have undergone an intense development in the last years. Fermentation or direct combustion and gasification are applied to convert biomass into electrical and/or thermal energy. Different kinds of combustors are widely available and can produce from a few kilowatts to up to 100 MW through direct combustion [40]. Large biomass gasification units have also been successfully implemented, sometimes co-fired with fossil fuels, with energy productions from 50 kW to 5 MW each. Researchers have proven the suitability of several technologies and approaches to valorise the by-products. Furthermore, different technologies can also be combined to achieve the desired results [41–43]. More details on this aspect can be found in our previous work [11]. In Italy, small-scale gasification plants are abundant in the alpine South Tyrol region [44], while combustion is more widespread in the rest of the country.

The economical convenience of a power plant is as crucial as its energy performance. The initial investment is especially high for large plants, and operating costs are greatly affected by the biomass transport and pre-treatment. Small and medium plants, often designed for energy communities [45–47], usually have a lower initial capital costs and less difficulties in obtaining the biomass. However, their efficiency is usually lower and may rely on the valorisation of sub-products to be economically sustainable.

A standardised parameter to compare the costs of the different energy sources is the levelised cost of energy (LCOE) [48]. The LCOE is defined as the total cost value of building and operating a power facility throughout its entire useful life. It measures the total costs that the installation will have during its life and divides them by the energy production that it will produce during its years of operation (normally expressed in USD/€ per megawatt hour). Key inputs to calculate LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type [48]. Incentives and tax credits also affect the calculation of LCOE. This parameter is increasingly used to compare the costs of new and renewable energy technologies with fossil fuel-based technologies. Three main factors need to be considered to assess biomass power generation: (i) feedstock type and supply; (ii) the conversion process; and (iii) the power generation technology.

A key cost consideration for bioenergy is that most biomass feedstocks have relatively low energy density. Therefore, collection and transport often dominate the overall costs of feedstocks. A suitable cost of electricity is achieved only if the feedstock is delivered within a certain distance around the plant. For biomass technologies, the usual share of feedstock cost in the total LCOE ranges between 20% and 50%. Planning and construction costs, fuel processing and preparation technology, and other equipment constitute the majority of the total investment costs of a biomass power plant.

The costs of electricity generation from a given technology vary widely across countries or locations. At a global level, the weighted average LCOE of bioenergy for power projects ranged from USD 76/MWh (2010) to USD 66/MWh (2019), nearly equivalent to the cost of electricity from new fossil fuel-fired projects [49]. More precisely, the weighted-average LCOE of biomass-fired electricity generation at local level is shown in Table 9. For comparison, the lowest value of fossil fuel-fired power generation plants (coal-fired) is USD 50/MWh.

Table 9. Weighted-average LCOE of biomass-fired electricity generation and comparison with other renewable technologies (2019). Data adapted from [49], ISBN 978-92-9260-244-4.

Region	$LCOE_{biomass}$ (USD/MWh)	$LCOE_{onshorewind}$ (USD/MWh)	$LCOE_{solarPV}$ (USD/MWh)
India	57	49	63
North America	99	51	155
China	59	46	67
Europe	80	67	120

In general, biomass can provide competitive electricity, provided that capital costs are relatively low and feedstocks are low-cost, as it is the case of Italy. The most competitive projects employ residues from forest or agricultural activities, available near the industrial processing sites. In the specific case of Italy, these technologies sometimes supply heat either to local industries, or district heating networks, with the revenues from these sales lowering the LCOE below the indicated values. Also, new applications and markets for sub-products (i.e., char, ash) would help in lowering this economic indicator.

Finally, in addition to technological and economic considerations, the social acceptance must always be carefully taken into account. Although the majority of Italian people are concerned about the climate emergency and in favour of renewable energy [50], new installations often encounter opposition from citizens and local politicians. Prosperi and colleagues [51] focused on this aspect in a recent article, dealing with the installation of a small agro-energy system in Apulia, and proposed some considerations to take into account when building a new plant. According to the review by Segreto et al. [52], some key aspects are building trust in the principal actors and properly informing citizens regarding cost-effect analyses and mitigation strategies.

4. Biomass Thermochemical Conversion in Southern Italy

4.1. Current Production of Electricity and Heat

Renewable energy from biomass has a good share in Southern Italy. A total of 63,762 units have been analysed and categorised (the complete list can be found in Tables S1 and S2) according to the employed technology and produced energy: power plants for electricity production or cogeneration plants for combined heat and electricity production (53 plants) and thermal units for heat production (63,709 units). The only feedstock considered has been solid biomass, while other biomass kinds (municipal waste, biogas or bioliquids) have been excluded. Figure 2 shows a map of the studied regions and the exact location of the plants for electrical production. Table 10 summarises the number and capacity of plants for electricity and heat production from solid biomass of the studied regions.

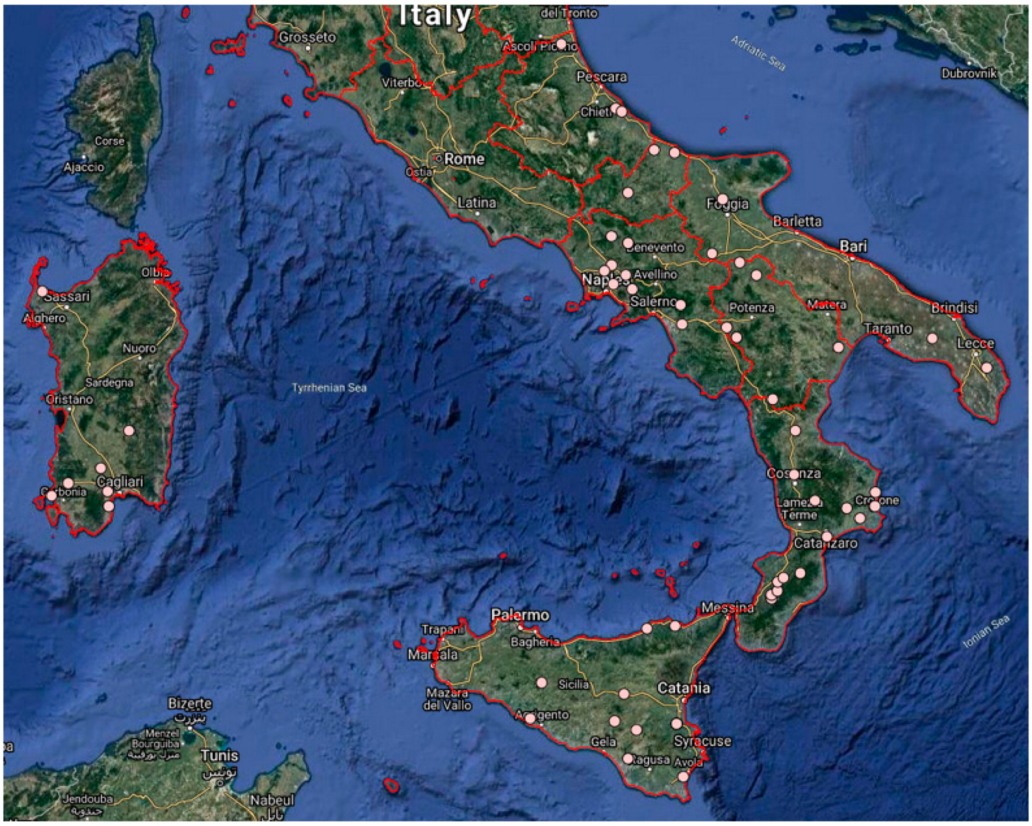


Figure 2. Location of plants for electricity production from solid biomass in Southern Italy (Source: GSE Atlaimpianti [53]).

In 2018, the production of electrical energy in Southern Italy was 96.087 TWh: this amount was was 34.34% of the overall Italian production [54]. Figure 3 summarises the electrical energy production of each region, together with the amount of energy that was imported from or exported to other Italian regions. Apulia and Calabria are the two largest producers and the largest exporters of energy. Campania and, to a lesser extent, Sicily are the least independent, importing large amounts from neighbour regions. Apart from these two cases, southern regions show a good degree of energetic autonomy [54].

Table 10. Number and power output of solid-biomass-to-energy units (Source: GSE Atlaimpianti [53]).

Region	N. of Plants for Electrical Production	Total Electrical Output (kW)	N. of Units for Thermal Production	Total Thermal Output (MW)
Abruzzo	8	3584	11,224	195.491
Apulia	9	51,224	4384	77.198
Basilicata	5	4188	5263	95,981
Calabria	10	194,996	7888	171,420
Campania	1	2774	12,510	250,041
Molise	3	15,519	3030	56.602
Sardinia	4	35,940	8096	122,189
Sicily	13	32,646	11,314	174.056
Italy	381	1,542,513	115,569	1,042,566

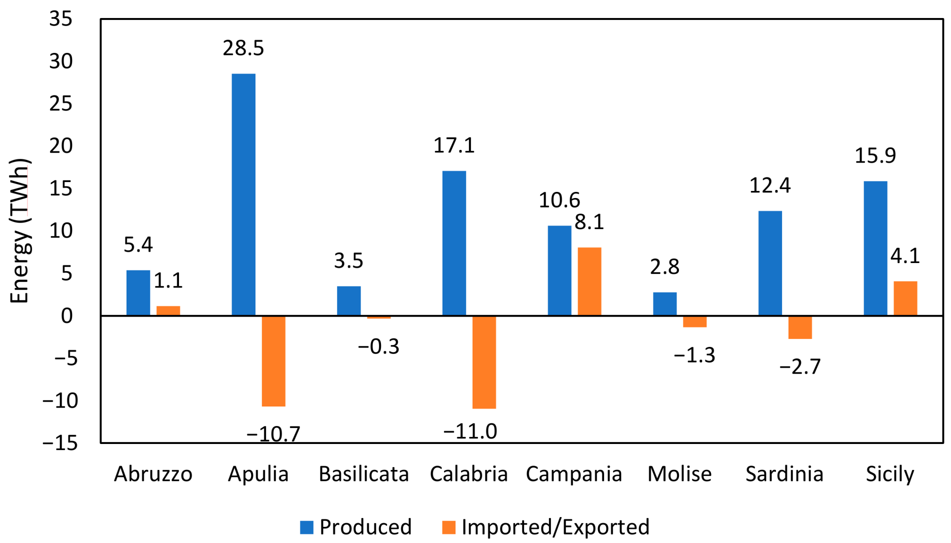


Figure 3. Production and import or export of electricity in Southern Italy (data adapted from [54] by Terna spa, www.terna.it).

Of the produced electricity, 37% is obtained from renewable sources, which is again in line with the national value (41%). Figure 4 displays the provenience of the electricity in the studied regions; the plot permits to point out several interesting facts. Only Basilicata and Abruzzo generate more than half of their electricity from renewable sources: for the former this is thanks to the large amount of wind energy, while for the latter it is thanks to hydroelectric energy. The other regions are mainly dependent on non-renewable sources, with Sardinia being the less virtuous one. Apart for Abruzzo, wind is the main source of renewable energy in all regions. Biomass energy is the most abundant in Campania and the least abundant in Sicily.

Finally, Figure 5 displays the provenience of the bioenergy per region (that is, the green slice of Figure 4). In terms of share in the bioenergy production, solid biomass represents the majority in Calabria, Molise and Sicily. In terms of electricity generated from solid biomass, however, Calabria is by far the largest producer, followed by Apulia. Sicily, Sardinia and Molise provide lower amounts while Abruzzo, Basilicata and Campania generate almost negligible amounts. With regard to the conversion pathway, all the largest plants convert the biomass through combustion. According to the latest IEA Bioenergy report on the status of thermal gasification of biomass and waste [55], Southern Italy hosts 27 gasification units, which is only 12.4% of the ones installed in Italy as of 2019. Every southern region has at least one gasifier, but they are all small- to micro-sized: the combined and average nominal powers are 4244 and 157 kW_{el}. respectively. Hence, the combined nominal power of biomass gasification plants is about 13% of all Southern Italy plants.

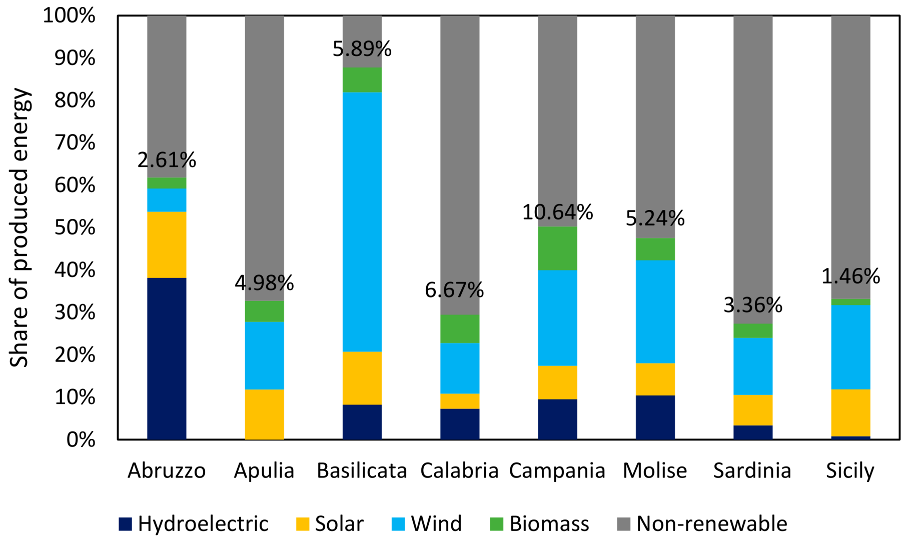


Figure 4. Source of electricity in Southern Italy; the percentages emphasise the share of bio-energy (data adapted from [54] by Terna spa, www.terna.it).

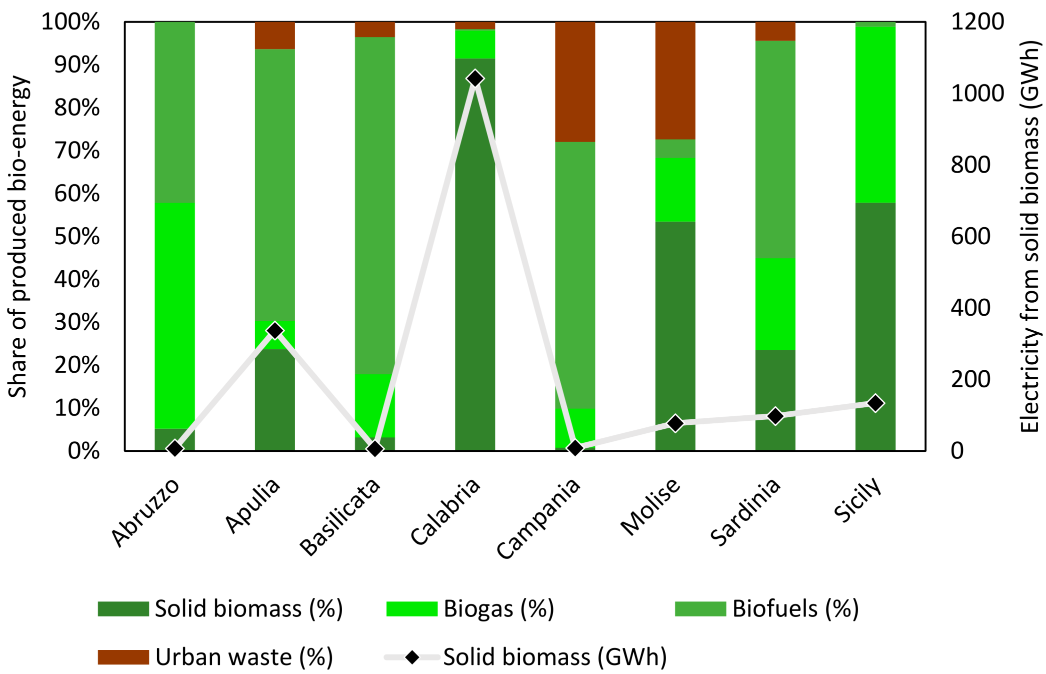


Figure 5. Source of bio-electricity in Southern Italy (data adapted from [54] by Terna spa, www.terna.it).

Table 11 summarises the value of heat production (both residential and non-residential) from solid biomass and the consumption of solid biomass for domestic purposes [56]. Southern Italy produces roughly 1/3 of the biomass heat that is generated in Italy, which is coherent with the fact that it hosts 1/3 of the inhabitants. The performance of Southern Italy is in line with the national average, although the regions perform markedly different from one another. In absolute terms, Campania and Calabria are the largest producers, but Basilicata, Molise and Abruzzo generate the highest amount per capita. Calabria has instead the largest use of solid biomass per inhabitant, followed by Basilicata and Abruzzo. In terms of heat generated per biomass unit mass, the differences are noteworthy: Sicily is the worst performing region with only 1.91 MWh/kg, while Apulia is the best with 7.73. Such a wide divide cannot be ascribed to the possibly different employed biomass and is likely to be a sign of inefficient conversion technologies. Another worrisome aspect is that the amount of wood employed for domestic heating is much larger than the amount that we identified as sustainably harvestable (as per Table 7). Not only this wood is burned in small domestic units, with low efficiencies and significant emissions, but it is likely to be imported from other regions or abroad, in a rather unsustainable fashion. This proves the need for better ways to provide heat for domestic purposes, such as district heating through co-generation, which would improve the efficiency and reduce emissions.

Table 11. Heat production from solid biomass and domestic use (partially adapted from [56] by GSE, www.gse.it).

Region	Heat Production from Biomass (GWh)	Heat Production from Biomass per Inhabitant (MWh/inhab.)	Domestic Solid Biomass Use (10^3 t)	Domestic Solid Biomass Use per Inhabitant (kg/inhab.)	Generated Heat per Converted Biomass (MWh/t)
Abruzzo	3822	2.93	982	752	3.89
Apulia	2953	0.74	382	95	7.73
Basilicata	1723	3.09	482	865	3.57
Calabria	5213	2.71	1766	918	2.95
Campania	6402	1.11	908	157	7.05
Molise	912	3.02	190	629	4.8
Sardegna	3084	1.89	843	517	3.66
Sicily	1658	0.33	868	175	1.91
Southern Italy	25,766	1.26	6421	313	4.01
Italy	75,106	1.25	19,738	328	3.80

4.2. Potential Production of Energy from Solid Biomass

Merging the data from Sections 2 and 4.1 may help understanding which Southern Italy regions are satisfyingly exploiting their biomass potential and which ones are more deficient in this aspect. To do this, countless scenarios may be hypothesised, so we decided to focus on two cases that may be the upper and lower boundaries of what may be actually feasible:

- In the most conservative (MC) scenario, we employed the ENEA values for the available forest biomass (Table 5) and considered that only 1/3 of agricultural residues (as per Table 8) could be available for energy generation. This biomass is converted into electricity with a 20% efficiency.
- In the least conservative (LC) scenario, we considered the values that we calculated for the sustainably harvestable forest biomass (Table 7) and 80% of the agricultural residues (as per Table 8). These are converted into electricity with a 30% efficiency.
- In both cases, we considered a low heating value of 14 MJ/kg for all types of biomass. This value is dependent on the biomass properties but is generally higher. Thus, even the LC scenario is rather prudent.

Table 12 summarises the results of this analysis. The amount of energy generated in the MC scenario is about 1/3 of the LC scenario for almost all regions. Looking at the single regions, Calabria is the best performing compared to its potential: it is already producing 216% of the energy we hypothesised in the MC scenario, and 69% of the LC one. This is a remarkable result, provided that the biomass is collected in a sustainable way and processed within a short-range chain. All the other regions appear to be markedly far from exploiting their full potential, which could make them more energetically independent and foster their economy and jobs abundance. Abruzzo, Basilicata and Campania appear to be the worst performing ones: even in the most conservative case, they produce only 3% of the electricity that the solid biomass potential of their territory would allow. While Abruzzo and Basilicata are energetically independent thanks to their large productions of hydroelectricity and wind electricity, respectively, Campania imports great amounts of energy and would benefit the most from valorising its solid biomass.

Table 12. Possible production of electricity from solid biomass in Southern Italy.

Region	Possible Electricity from Forests (GWh/y)		Possible Electricity from Agricultural Residues (GWh/y)		Possible Electricity from Solid Biomass (GWh/y)		Current Production/Possible Production (%)	
	MC	**LC**	**MC**	**LC**	**MC**	**LC**	**MC**	**LC**
Abruzzo	46.8	282.7	147.5	353.9	194.2	636.6	3.7	1.1
Apulia	36.1	92.7	616.8	1480.2	652.9	1572.9	51.7	21.4
Basilicata	50.8	193.0	131.8	316.4	182.6	509.4	3.5	1.3
Calabria	119.6	634.1	363.0	871.2	482.6	1505.3	216.0	69.3
Campania	93.2	349.4	171.8	412.3	265.0	761.6	3.2	1.1
Molise	34.0	96.4	57.5	138.0	91.5	234.4	84.7	33.1
Sardinia	50.6	434.5	105.2	252.4	155.7	686.9	62.9	14.3
Sicily	19.9	200.3	389.2	934.0	409.1	1134.3	32.8	11.8
Southern Italy	451.0	2283.1	1982.6	4758.3	2433.6	7041.4	70.3	24.3
Italy	1696.0	9993.6	5630.5	13,513.3	7326.6	23,506.9	56.8	17.7

The final consideration is that all the regions would benefit from creating co-generation (or tri-generation) plants and distributing the produced thermal energy through district heating. This would provide a more efficient way to heat (or cool) buildings and limit the current tendency of burning vast amounts of solid biomass in small domestic units. Southern Italy regions indeed do not have any district heating grid.

4.3. Power Plants by Type and Region

The following national official sources have been consulted: Gestore Servizi Energetici (GSE), Trasmissione Elettrica Rete Nazionale (TERNA), Federazione Italiana Produttori di Energia da Fonti Rinnovabili (FIPER) and Italian Biomass Association (ITABIA). Moreover, specific data have been provided by consortiums of producers, such as Tecnologie Innovative per il Controllo Ambientale e lo Sviluppo Sostenibile (TICASS). The following sub-sections highlight the key points of each of the studied regions, while the complete list can be found in Table S1.

4.3.1. Electricity Production

Abruzzo

Abruzzo generates a very modest amount of electricity from solid biomass compared to its potential (as per Table 12), and it is roughly tied with Basilicata and Campania as the worst performing region. Although in recent years the government of Abruzzo seems to have investigated the possibility of promoting new solid biomass plants [57], the region's energetic plan dates back to 2009 [58] and new plants are still lacking. This may partly be due to the dramatic earthquake that hit the capital city L'Aquila in 2009, causing the destruction of a large portion of it, and the subsequent and still incomplete re-building efforts.

According to the consulted sources, Abruzzo hosts eight plants that produce electricity from solid biomass. Their combined nominal power is 3.6 MW, with an average value of 0.49 MW. All of them are small sized: the largest ones are located in Treglio (CH) and Monteodorisio (CH) and have a nominal power of 0.999 MW_{el}. We were not able to gather further information about the plants.

Apulia

Apulia ranks 2nd in Southern Italy and 6th in Italy in terms of electricity production from solid biomass, with 337 GWh in 2018. According to the consulted sources, Apulia hosts 9 plants that generate electricity from solid biomass, for a total of about 51 MW_{el} that are mainly produced by the three largest plants.

Apulia's largest solid biomass plant (and one of the largest in Italy) is located in Sant'Agata di Puglia (FG) and is owned by the company Linea Green SPA [59]. The plant has a nominal power of 25.2 MW_{el} and produces more than half of the solid biomass electricity of the region (184 GWh/y). It is fed with 150,000 t/y of residual biomass, mainly cereal straw that is produced in abundance in the surrounding area. Other kinds of woody biomass (olive pruning or forest residues) are employed in a lower share. The heat is thus far not employed, but there are plans to exploit it for domestic or greenhouse heating.

Foggia (FG) hosts the second largest plant (13 MW_{el}), which is owned by Enterra SPA [60]. The plant employs 130,000 t/y of short range (within 70 km) biomass, which is obtained from various kinds of agriculture and forestry residues. Another large plant is located in Monopoli (BA) and is owned by Ital Green Energy srl [61]. It is part of a group of three plants of the company that produce electricity from biomass, but it is the only one employing solid biomass. Its nominal power is 12 MW_{el} and employs about 100,000 t/y of biomass, mainly olive wood and pomace.

Fiusis srl owns a smaller plant (1 MW_{el}) in Calimera (FG), which only employs short-range residues from olive pruning to generate electricity and heat, also producing wood pellets that are sold for private use [62]. This plant was described in better detail in a recent article by Palmieri and colleagues [63], who also focused on the encouraging environmental and economic performance of the plant. Another peculiar plant is located in Torre Santa Susanna (BR): it has a nominal power of 0.2 MW_{el} and employs a gasifier to convert the biomass.

Basilicata

The share of electricity from solid biomass in Basilicata is almost negligible. In their recent review, Di Leo and colleagues [64] estimated that biomass should provide 13 to 21% of the region's renewable electrical energy to meet decarbonisation targets, with adequate promotion of new installations. Nonetheless, only five small solid biomass thermoelectric plants are registered in GSE, with a total nominal power production of 4188 kW. The maximum produced output is 1 MW_{el} obtained in two of the plants: Melfi (PZ) and Sant'Angelo Le Fratte (PZ). The latter is owned by the pellets production site Tan Pellets S.R.L [65] where a cogeneration plant powered by virgin woody biomass is present in addition to the production cycle. It consists of a boiler fueled by biomass, partly purposely purchased and partly coming from the residues from the production of pellets, and a turbo generator Organic Rankine Cycle (ORC) which provides 1 MW_{el} and 4 MW_{th} to the production plant to become an energetically auto sustained plant. The third largest size in the region is the plant located in Venosa (PZ) which provides a nominal power of 0.99 MW_{el}.

Among the small-sized installations, the plant in Bernalda (MT) (Ingeco Clean Energy Systems) produces 500 kW_{el} through an overheated water boiler at 150 °C. The plant has also three Clean Cycle 125 systems and three evaporative towers and it is part of a cogeneration structure for heating greenhouses. The system uses the waste biomass deriving from the collection of pruning and agricultural waste, in the province of Matera.

According to the IEA Bioenergy gasification report [55], Basilicata also hosts two plants that perform the gasification of the biomass. They belong to agricultural industries and are both in the Matera province: one is in Pomarico (0.3 MW_{el}) and belongs to Azienda Agricola Camardo, while the other is in Calvello (0.2 MW_{el}) and belongs to Azienda Agricola Isca. They are however not present in the GSE database, so it is unclear whether they are connected to the grid.

Calabria

A total of 10 major thermoelectric plants are listed in GSE, with a total nominal power production of about 195 MW. Eight plants produce an output equal to or higher than 1 MW whereas two produce less. The plants generate more than 1 TWh of electricity from solid biomass.

The main source of power in the region is the Mercure plant (Cosenza) (San Marco Bioenergie), a biomass plant located at Laino Borgo in the border between Calabria and Basilicata regions [66]. The plant requires a constant supply of about 350,000 tons per year of woody biomass for an annual net production of 280 GWh.

Biomasse Italia SpA oversees the biomass plant at Strongoli (KR) [67] which provides 51 MW_{el} using two fluidised beds for biomass combustion, able to process 81 t/h at 515 °C and a pressure of 100 bar of steam. In addition, the system has a fume treatment and ash abatement plant to limit atmospheric emissions below the established limits and a steam turbogenerator. E.T.A. SpA owns and runs the plant in Cutro (KR) [68] able to produce 16.5 MW_{el} from 150,000 tons of biomass. The technology is also based on combustion in a fluidised bed and successive steam generation cycle. The system is completed with a fume and ash abatement section.

Combustion in vibrating grids is also widely present in biomass-to-energy technologies. One example is the power plant of Crotone [69], owned and operated by Biomasse Crotone, a company acquired by EP New Energy Italia in December 2017, with a total capacity of 32 MW_{el}. The plant is mainly fed with biomass made of wood chips, derived from forest maintenance and agro-food residuals coming from local and national markets. The yearly biomass consumption is about 300,000 tons, and the total annual production at full capacity is about 220 GWh. Another example is the plant in Rende (CS). The thermoelectric power plant [70] was built by Silvateam and it is run now by the Falck Group and can provide up to 17 MW_{el} from feedstock composed by 60% wood and 40% exhausted olive residues. The combustion chamber receives 20 t/h of biomass and the produced steam reaches a maximum pressure of 60 bar at 480°C.

Three power plants produce 1 MW_{el} each: Taurianova (C&T S.p.a), Serra San Bruno (T.c.m S.R.L, [71]), Parenti (Nuova Energia Societa' Agricola). The Taurianova thermoelectric plant is powered by wood, pomace, citrus pulp and by-products derived from pruning and agricultural waste.

Campania

Despite the abundance of agricultural residues on its territory [38], Campania produces a very limited amount of electricity from solid biomass. The largest producer is, by far, the thermo-electrical plant in Casalnuovo di Napoli (NA). The plant is run by Comasa and the technology is based on combustion in mobile grids. It employs 30,000 tons of biomass per year and can produce 2774 MW_{el}.

Molise

Molise has been a next exporter of electrical energy since 2006, the year in which a large thermoelectric plant fed with natural gas was opened in Termoli (CB). The gas is however imported from abroad. Molise generates more than 2.5% of its electricity from solid biomass. Although Molise is far from taking full advantage of its potential, this is a positive result compared to other regions.

According to the consulted sources, there are three active plants generating electricity from solid biomass in Molise. One of them is quite large (14.5 MW_{el}) and is in the industrial area of Termoli (CB), which is Molise's only port. The plant was built in 2001 by C&T, has a moving grid burner and employs wood chips as its fuel [72]. Molise also hosts a plant in Montenero di Bisaccia (CB): the plant is owned by *Il Quadrifoglio Pellet* and produces 1 MW_{el} and 5.2 MW_{th} [73]. The heat is partly employed for an industrial laundry and partly to produce wood pellets, which are sold for domestic use. The employed biomass is obtained within a limited range in Molise and nearby regions. Finally, there is a very small plant (0.02 MW_{el}) in Molise (CB).

Sardinia

Sardinia has an average production of power from biomass on its territory. It has four power plants for a total of nearly 36 MW_{el}. The largest producer is the plant located in

Assemini ([74], 22 MW_{el}) followed by Serramanna ([75], 13 MW_{el}). The latter is supplied with various types of waste from the Mediterranean basin as pomace, pruning from olive growing or shells and peels of African palm and almond.

Sicily

With 134 GWh of electrical energy from solid biomass, Sicily ranks third among the Southern Italy regions. This energy is mainly produced by two large plants, while there are a few other plants that can generate 1 MW or less each. The overall nominal power is about 32 MW_{el}.

The largest plant is located in Enna (EN) and has a nominal power of 20.46 MWel (18.7 according to the company's website [76]). The plant features a fluidised bed burner and an elaborate gas cleaning unit. It originally employed short-range eucalyptus wood, but it is unclear whether this is still the case. The other large plant (9.8 MW_{el}) is in Agrigento (AG), but we were not able to find further information about it.

A smaller plant (1 MW_{el}) is in Caltagirone (CT) and converts agricultural and forest residues into electricity and heat, the latter being provided to nearby industrial activities [77]. All the other plants have capacities that are inferior to 200 kW_{el} and do not appear to possess any outstanding feature.

Heat Production

Table 13 shows the number of units (public and private) for heat production, their capacity and location, according to the GSE atlas [53]. Table S2 contains the most representative heating units (capacity > 100 kW) for each region.

Table 13. Heat production from solid biomass in Southern Italy. Data partially adapted from GSE Atlaimpianti Internet. https://atla.gse.it/atlaimpianti/project/Atlaimpianti_Internet.html [53].

Region	Number of Units (Public/Private)	Number of Units with Capacity > 100 kW	Total Installed Capacity (MW)	Averaged Installed Capacity (kW)
Abruzzo	2/11,222	2	195	17
Apulia	0/4384	2	77	18
Basilicata	1/5262	0	96	18
Calabria	1/7887	1	171	22
Campania	0/12,510	7	250	20
Molise	0/3030	0	57	19
Sardinia	3/8093	2	122	15
Sicily	1/11,313	0	174	15

5. Conclusions

Achieving a complete decarbonisation by 2050 will require a continuous transformation of the energy system in the forthcoming years. The most desired technologies will be those that can be flexible and adapt to the increasing energy needs in a sustainable, flexible, and reliable way. Efficiently managing forest and agricultural residues, still greatly under-exploited, is a possible way to do this. The development of improved combustors and gasifiers will also facilitate this activity. Finally, the economic viability of the processes will be enhanced by properly valorising sub-products. All these tasks require a suitable adaptation of the legislation.

With regard to Southern Italy, the area does not appear to be performing significantly worse than the rest of the country, apart for a few aspects such as the lack of district heating and gasifiers. The data indicate that solid biomass from forests and agriculture is a largely underexploited energy source, possibly except for Calabria. A more extensive and integrated management of biomass could bring noteworthy advantages: decarbonisation, energetic independence, reduction of waste, creation of new jobs and support for internal and rural areas.

In terms of electricity generated from solid biomass, Calabria is by far the largest producer, followed by Apulia. Sicily, Sardinia and Molise provide lower amounts while Abruzzo, Basilicata and Campania generate almost negligible amounts. For Campania the advantages of fostering solid biomass conversion appear as the most urgent, since it is the least energetically independent region of the area. All regions share a scarcity of gasifiers. Combustion is a more established technology and thus perceived as safer by investors. Nonetheless, gasification can be preferable to direct combustion, and should be pushed for new plants or revamp of old ones.

Heat generation from solid biomass is more widespread and homogeneous, although mainly done through small-scale domestic units. This is not an optimal situation, as these units are characterised by low efficiencies and are often fed with foreign biomass. The goal should be to replace these units by building small scale CHP plants and provide the heat through district heating, with higher efficiency and lower emissions. As a matter of fact, district heating is completely absent in Southern Italy.

Finally, as in our previous article, we wish to emphasise that while searching the internet for information on the plants, we also came upon several articles and petitions of citizens and journalists criticising bioenergy plants, demanding not to build new units and shutting down existing ones. We do not wish to comment on the merit of each case: there may indeed be instances of mismanagement, whether involuntary or malicious. Nonetheless, as described in this article, biomass thermochemical conversion can be done in a very safe way and is an irreplaceable contributor to a complete decarbonisation, with noteworthy advantages compared to other renewable technologies. Looking forward, the population should be properly informed and involved when a new plant is proposed, building trust in the principal actors and explicating cost-effect analyses and mitigation strategies.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/en14092576/s1, Table S1: Plants for electricity production from wood biomass in Southern Italy. Table S2: Representative plants for heat production from wood biomass in Southern Italy.

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