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Review

The Agro-Waste Production in Selected EUSAIR Regions and Its Potential Use for Building Applications: A Review

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Abstract: The purpose of this study is to provide a snapshot of the agro-waste production in Puglia, Molise, Albania and Montenegro, some of the regions belonging to EUSAIR (ADRIATIC-IONIAN REGIONS) correlating this aspect to the possible use of agro-waste in the building sector. EUSAIR is a functional area, facing the Adriatic sea, treating the marine, coastal and terrestrial areas as interconnected systems. In the first part of the paper, the state of the art about the current consumption of agricultural biomass is carried out referring to the ongoing research lines. It was shown that a great number of international studies have demonstrated that the agro-waste plays an important role in several fields. Moreover, several researchers conducted studies on hygrothermal, physical and acoustical properties of building materials made with biomass proving the potentiality to use this kind of by-product. Then, the state of the art regarding the production and current way of disposal of the agro-waste in the regions of the EUSAIR above mentioned was performed in order to outline the possible by-products which are suitable to be re-used in the building sector. The correlation existing between the agro-waste and the possible use in the building sector is finally presented, focusing on the legislative framework currently existing in each of the regions.

Keywords: agro-waste; sustainability; building materials; re-use; recycle; circular economy

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1. Introduction

According to World Bank previsions, it was assessed that by 2050, the world will be consuming resources as if there were three [1]. As a matter of fact, consumption of biomass, fossil fuels, metals and minerals are predicted to double in the next forty years, with an annual waste production expected to increase by 70% by 2050. The European Green Deal strategy [2] has launched a complementary and multi-disciplinary plan.

Half of total greenhouse gas emissions, the biodiversity loss and water stress come from the resource extraction and processing. Thus, the European Union has given priority to circular economy policies providing research support on the waste-related topics correlated to re-use and recycle challenges [3].

The promotion of the circular economy is one of the main pillars of the European plans [4], fundamental to achieve climate neutrality by 2050; the target to reach is the economic growth together with the sustainable development. The action plan (2020) [2] demonstrates that the circular economy has the potential to increase EU GDP by an additional 0.5% by 2030 creating approximately 700,000 new jobs.

From this perspective, it must be considered that the traditional method to dispose the biomass represents a big issue. The biomass can be distinguished in livestock residues, food waste by-products, sludges derived from the industrial activities and agricultural waste derived from pruning [5]. Nowadays, considering the agricultural waste, the improper treatment of these by-products causes several environmental problems mainly due to burning in field. Agro-waste burning, in fact, has a significant impact on environmental quality, public health, and climate change worldwide. This practice causes the emission of particulate pollutants as CO_2 and CO, and fine particulate matter (PM), provoking a hazardous impact on human health due to respiratory and cardiovascular diseases. Conversely, this biomass waste might be used for several beneficial purposes.

Due to the presence of nutritional components, such as flavonoids, polyphenols and fibers, some of these by-products are suitable for animal nutrition or can represent an added value in the make-up industry.

Moreover, they can be treated by the anaerobic digestion technique for energy recovery or they can be reconverted in feed stock for energy production and nutrients for intensive agriculture. On one hand, some studies have proved the significance and the potentiality of using agro-wastes in the energy sector [6,7]. Khan et al. [6] stated that biomass accounts for only about 9% to 14% of energy sources in industrialized and developing countries.

Pereira et al. [7] demonstrated that biomass energy production could be regarded as a renewable energy process not emitting additional carbon dioxide into the ecosystem. On the other hand, the potential use of the agro-waste in building components plays an important role for the sustainability. It was demonstrated that by-products derived from the agriculture constitute a sustainable alternative as aggregates in construction instead of cement [8,9]. Ismail et al. [8] demonstrated that by replacing 10 to 30% of cement with agro-waste, it is possible to achieve high-strength concrete.

Several countries with an agricultural vocation are paying a lot of attention to the proper utilization of agricultural waste. Asdrubali et al. [10] found that in Thailand, for example, the utilization of palm oil ash is a great concern, as the palm oil industry plays an important role in local agro-industries.

On the basis of the considerations above mentioned, the main goal of the present paper is to describe the state of the art regarding the production and current way of disposal of the agro-waste in some regions of the EUSAIR (Puglia, Molise, Albania and Montenegro). The selection of the regions above mentioned was performed considering that agriculture is one of the main activities of these areas. Moreover, according to Koppen-Geiger climate classification [11], all the regions are mostly characterized by similar climate areas, including hot summer Mediterranean (Csa), humid subtropical climate (Cfa) and temperate oceanic (Cfb), which also result in comparable agricultural vocation. Therefore, a brief analysis of the agriculture and the type of by-products derived precedes the description of the possible uses and applications of the biomass in the building sector. A focus on agro-waste production in each region is then carried out in the different areas under study, in order to outline the possible by-products suitable to be re-used in the building sector.

2. Materials and Methods

The presented research was performed with a multi-phase process, conducted on more fields. The aim was to correlate two different aspects of the topic. Three different fields of search were followed. At first, the research was performed by taking into account the agro-waste production in the countries involved in the project. This kind of analysis was carried out by examining the data extracted from the databases of national statistical institutes, such as ISRPA Istituto Superiore per la Protezione e la Ricerca Ambientale (Rome, Italy), MONSTAT Statistical Office of Montenegro (Podgorica, Montenegro), INSTAT Institute of Statistics (Tirana, Albania) and elaborating them to achieve a panoramic view of the national trend resulting from the evaluation of main categories of agricultural products and the main agro-waste achieved in the recent years of 2018, 2019, 2020.

The second step was carried out in order to collect data in terms of existing local, national and European standards about energy-saving applied to the buildings. In particular, this kind of research allowed to clarify the contribution of sustainable materials in terms of energy-saving when applied to the opaque building envelope. It was developed as research on institutional platforms of each country. Afterward, with the aim to build the state of art about the possible use of agricultural residues, the topic agro-waste re-use and recycle was searched consulting the following electronic databases: Web of Science, Google Scholar, Scopus, ResearchGate. The search was performed using different combinations of material-and properties-related and application-related keywords as shown in Table 1. Thus, the total records obtained consisted of 136 documents, which were cross-screened in order to eliminate records not concerning the topic of the paper. Finally, the total documents selected were 61 research references to develop the structure of the present paper.

Table 1. Keywords used for research in electronic databases.

Material-Related Keywords	Application-Related Keywords
Agricultural components	Building components
Biobased material	Building material
Biomass	Sustainable architecture
Waste	Insulation panels
Raw matter	Building envelope
Thermal conductivity	Sustainable bricks
Thermal properties	Lightweight mortar
Acoustic properties	Agro-waste-based plaster
Laboratory tests	
High energy efficiency	

3. Agriculture and Agro-Waste

According to the World Health Organization (WHO), agriculture includes several activities such as growing, harvesting and primarily, processing of crops. In the definition of agriculture activity, the cure of the animal can be considered [12]. Agriculture is the largest contributor to the economy of many European countries.

According to Lim et al. [13] agro-waste can be produced from various agricultural activities. These by-products can include the livestock farming waste besides leaves and vegetable matter [5]. Agro-waste produced by farming activities is considered useless and it is usually discarded. The disposal of the agro-waste, in general, represents a great concern because it may affect human health and safety and it can be dangerous for the sustainability of the environment. Currently, in the EUSAIR region, the usual agricultural waste disposal methods consist in burning, dumping, land-filling and random piling generating environmental pollution [14]. One of the greatest issues is represented by the particulate matter (PM). It can be defined as the fine solid matter dispersed in the air; it is generated also during the agricultural operations and processes. Human health may be affected when the PM particles are inhaled by the lungs. Particles smaller than 10 µm in aerodynamic diameter (PM10) can be produced by the burning in field. The burning of the stubbles is one of the practices most adopted to clean the fields from the harvest leftovers. Moreover, in areas where a second crop production takes place, stubble-burning practice reduces the time of planting. However, the smoke produced from burning in field is very hazardous for the people living in adjacent areas.

Esparcia et al. [15] asserted that most of the waste comes from the building sector (33.5%) and the mining and quarrying sector (29.8%). The households cover 8% of the total waste production. Agriculture, forestry and fishing take up the shortest part of the list, reaching just 1.4% of the total waste production. Bedoic et al. [16] studied agro-waste classifying them in Agricultural Waste, Co-products and By-products (AWCB) underlying the role assumed in the world's production of animal feed. The authors presented the estimated quantity of AWCB per capita classifying them in four categories (fruit, vegetable, cereal, animal) from 2010 to 2016 (Figure 1).

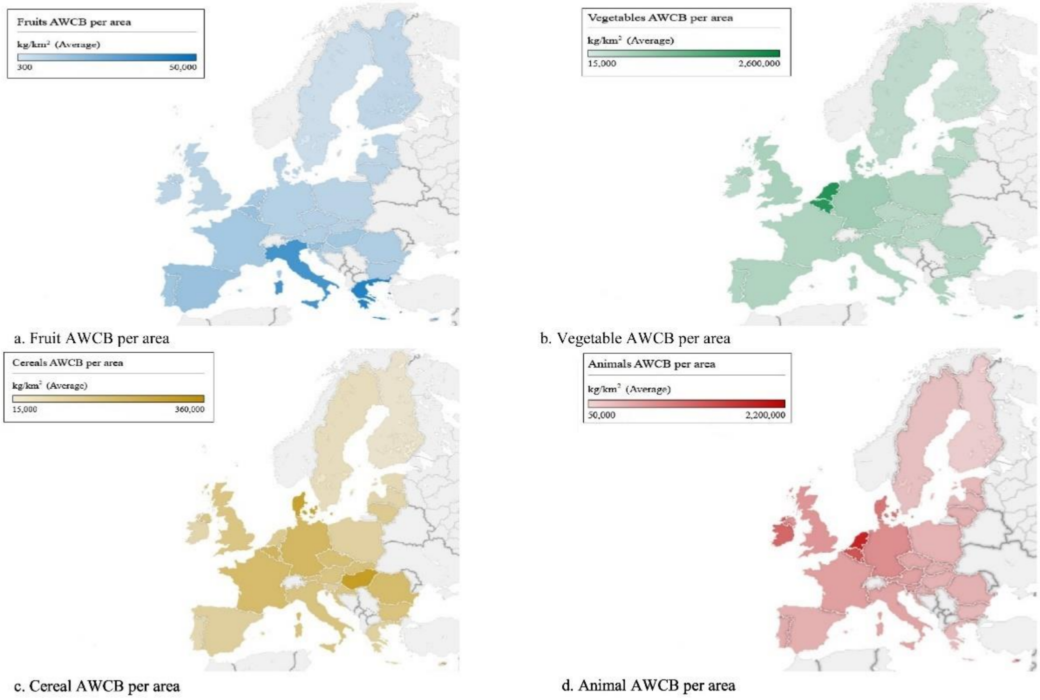

Figure 1. The average quantity of AWCB produced in Europe from all sectors per area in the period 2010–2016: Fruit AWCB (**a**); Vegetable AWCB (**b**); Cereal AWCB (**c**); Animal AWCB (**d**). (Source: Bedoic et al. [16]).

Sortino et al. [17] reported that municipal bio-waste could substitute the synthetic chemicals for the depollution of contaminated soil and waters. Malico et al. [18] evaluated the positive effect derived from the use of forest and agricultural residues for the production of bioenergy in the rural area of Portugal. Asdrubali et al. [10] demonstrated that the biomass residues assume an important role in the production of insulation materials for building applications.

4. Re-Use and Recycle: Building Applications

Liuzzi et al. [19] stated that the building sector, according to the current international plan and strategies is "obligated" to use "greener" and more sustainable materials, that involve the use of natural and bio-based raw matter which can significantly reduce the impact on the environment, also improving indoor quality with the abatement of the energy consumptions. Within this framework, bio-based materials obtained from agricultural by-products represent an interesting alternative to those derived from fossil carbon [20]. As indicated by numerous studies, there are several possible ways to re-use agro-waste. In parallel, these agro-industrial wastes are full of biological and nutritional components, such as polyphenols, flavonoids, carotenoids, fibers and carbohydrates [21]. Thus, some of these residues are suitable as a supply of protein and calories in animal nutrition. The development of biomass-based building materials is one of the main topics of recent researches [22–27]. Liu et al. [28] performed an analysis of the studies regarding the potential use of the agro-waste as a building component. It was demonstrated that several applications are feasible using the agricultural waste as raw matter: panels, blocks, vegetable biomass, multi-layer solutions, particles, slurries and coils.

Usually, biomass resulting from pruning in the field needs extra treatment; they were dried and smashed or crushed. Conversely, other kinds of residues, like straws, can be used directly as they are. Finally, the scraps are mixed with other components or treated by chemical agents to achieve fire resistance, mechanical, acoustic and thermal properties. Different manufacturing methods currently exist. Liu et al. [28] classified the production methods into seven different categories as summarized in Table 2: bonding molding, pressing molding, hot-pressing molding, injection molding, foaming molding, in natural (original/raw) form and others. The manufacturing method called bonding molding requires the use of at least one chemical binder, while the curing process takes place at environment temperature and pressure. The hot-pressing molding does not require any kind of binder, but high temperature and pressure are used to bind the different components. The injection molding involves the use of liquid form solution injected into a mold, while the curing time is longer than in the other cases.

Table 2. Typical manufacturing method (adapted from [28]).

Manufacturing Methods	Argumentation
Bonding	The method involves binder to join the single particles in order to create different mix design.
Pressing	The method involves the pressing at environmental temperature.
Hot-pressing	The method involves pressing at high temperature to change the chemical compositions of the particle and join them together.
Injection	The method involves the introduction of a liquid solution to join the particles.
Foaming	The method involves the use of foam to cover the internal pore.
Real form	The fibers are joined as they are in the real state (e.g., pruning waste bales).

Prusty et al. [29] described the possibility to use agro-waste like sugarcane bagasse ash, giant reed, groundnut shell, oyster shell, rice husk ash and cork as concrete aggregates in order to improve the physical properties. The major differences occurring between these residues are the place of collection and the conversion processes to transform them into a fine aggregate.

Figure 2 shows the steps of the process of conversion of different agricultural by-products, used in the Building Physic Laboratory of Politecnico di Bari. The vegetable biomass, derived from agricultural in-field processing or agro-industrial processing, is converted into new raw matter as lightweight aggregates or main components of sustainable bricks or insulation panels.

Straw is an agricultural by-product derived after removing treatment of grain and chaff [19]. Different types of straw exist, based on the cereal crops such as barley, oats, rice, wheat and rye.

Processing olives produces several by-products. One of the residual biomass of olive processing is obtained during pruning and harvesting and it is a mix of woody particles and some small branches and leaves [22,26].

The almond skin residues are achieved after peeling the almonds at high temperature; then the brown skin, in form of a thin layer, is taken off and stored in tanks before the final disposal [30].

Asdrubali et al. [10] illustrated the state of the art of the main hygrothermal and acoustic properties of innovative building materials developed with natural fibers (i.e., bagasse, cotton, straw), demonstrating that most of them have very interesting properties and potential to be used in practice.

Liuzzi et al. [30] studied the physical, acoustical, and thermal performances of composite panels created by almond skin residues, extracted after the industrial manufacturing process of the almonds (Figure 3). The collected data and experimental results allowed to assert that the investigated materials were comparable to similar products currently used in building construction.

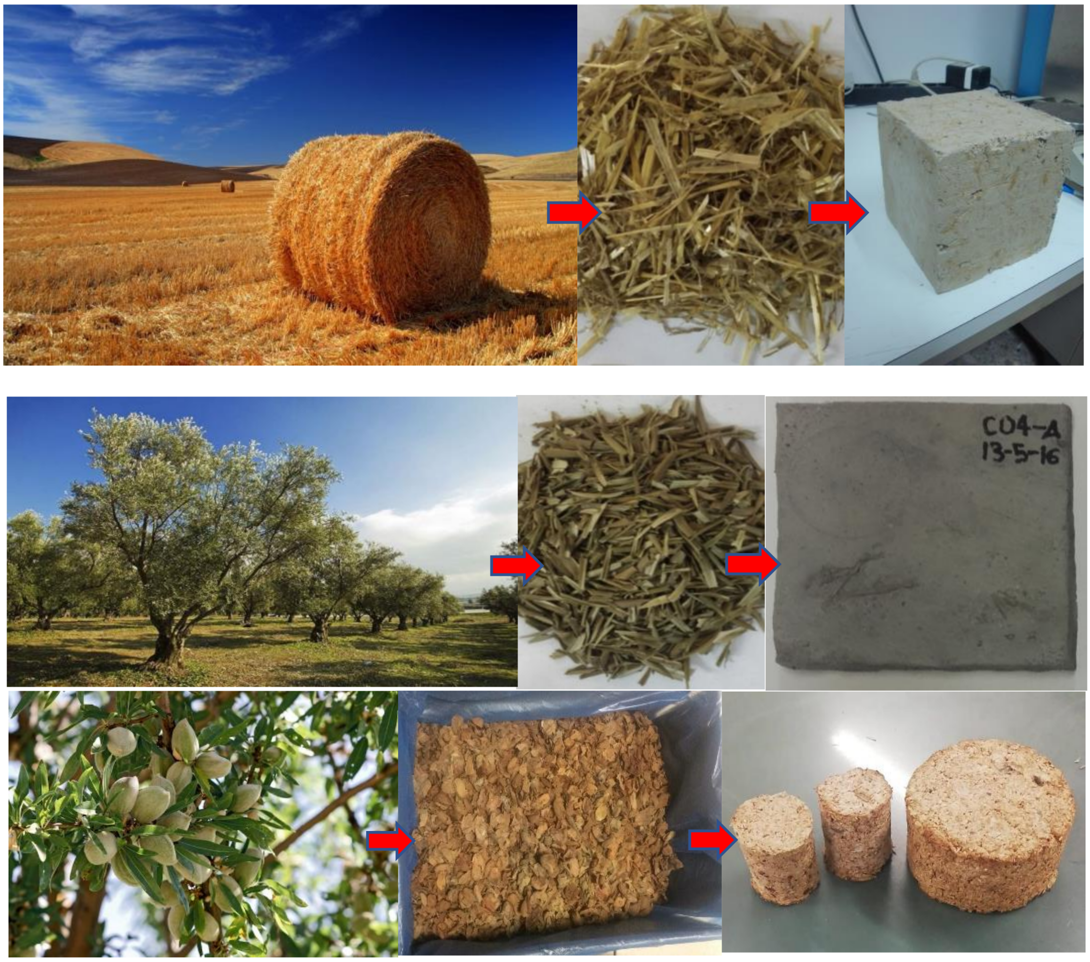

Figure 2. Processes adopted to produce building materials with raw matter from different agro-waste used in Building Physic Laboratory of Politecnico di Bari. (From top to bottom: straw fibers, olive waste fibers, almond skin waste).

Figure 3. Sound absorbers made with almond skin waste (Liuzzi et al. [30]).

A number of common issues have emerged by a review of international literature on agricultural waste use.

Fibrous agricultural materials are suitable for thermal and acoustical purposes [30]. However, due to the non-homogeneous structural characteristics of some natural fibers, different configurations and binders should be undertaken to identify reliable combinations. The manufacturing process is one of the factors affecting the characteristics of insulation materials. Several possible combinations of different agro-waste are eligible to be used in the construction industry for bricks, panels, mortars, etc. Balador et al. [31] summarized the key issues emerging from different literature studies providing a synthesis of advantages and disadvantages of the use of agro-waste by-products for building insulation [31]. They reported between the advantages of the good thermal properties and the biodegradability, focusing on the abundance and the renewability. On the contrary, about the negative aspects, they included a scarce load-bearing performance and the possible presence of contaminants.

5. Agro-Waste Production and Use in the Building Sector

Recently, a significant increase of solid waste produced by domestic, industrial and agricultural activities was caused by the rapid growth of population. Recycling agro-waste is one of the key issues to meet the future EU targets to enact the circular economy approach [2]. The way and the level of collecting bio-waste differs considerably across Europe. Many European countries have already implemented the separate collection of agro-waste, but unfortunately, a great number of regions are still far from separating agro-waste, not knowing the full potential that could have "new" raw matter.

As mentioned in the previous sections, innovative research lines are arising for converting agro-waste into new raw matters pointing at higher challenges for the circular economy. The next section shows an overview of current agro-waste production in four Adriatic regions, namely Puglia, Molise, Montenegro and Albania. Their choice, dictated by involvement in an ongoing EU project, provides a comprehensive picture of different climatic scenarios, cultivated species, cultivation techniques and national regulations.

5.1. Puglia and Molise

In Italy, the Registry of the Waste was instituted by Article 3 of the National Decree 9 September 1988 [32] n.397, converted, with changes, by the law on 9 November 1988, n.475 [33]. The Registry is organized in a national section by the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) and in regional sections. Furthermore, a telematic registry exists. According to the current law, the wastes are classified, referring to the origin, in urban waste and special waste. Figure 4 shows the life cycle of special waste.

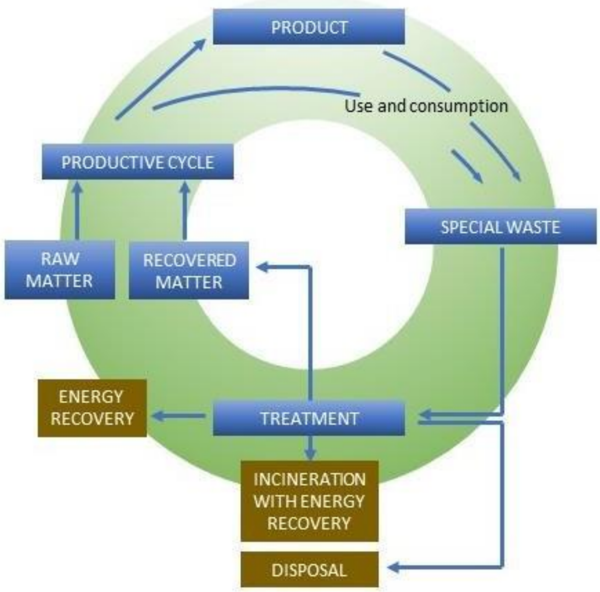

Figure 4. Special waste life cycle.

In terms of the riskiness, they are classified in hazardous and non-hazardous waste (Figure 5). The Article 184, sub 3 of the Legislative Decree n.152/2006 [34] states that the agricultural residues belong to the category "special waste". In this category, residues derived from agricultural, agro-industrial, sylviculture and fishing activities are included.

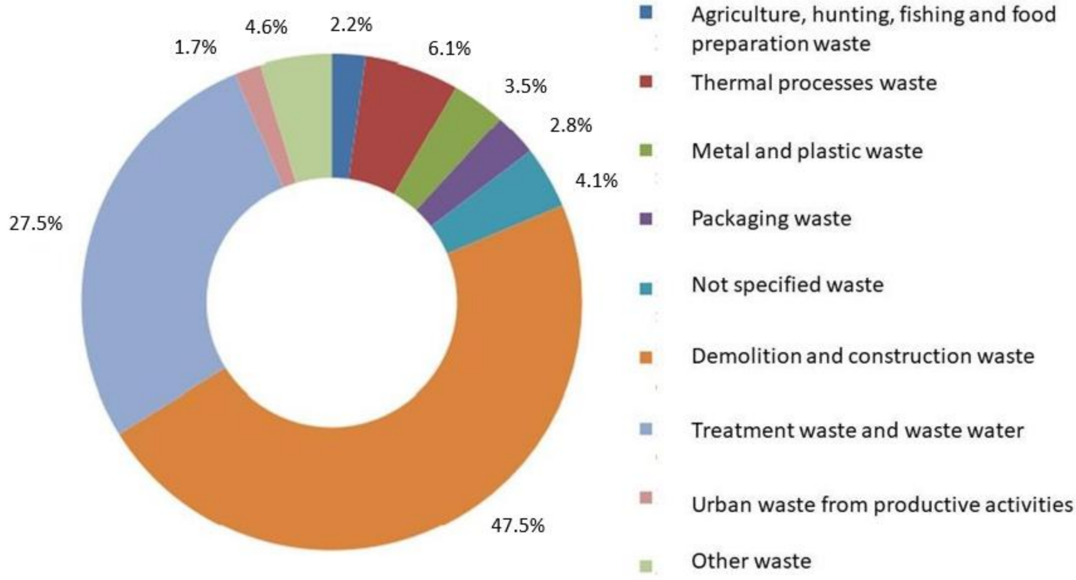

Figure 5. Italy, percentage repartition of non-hazardous urban waste per waste type. (Adapted from Rapporto rifiuti speciali, ISPRA [35]).

The Italian institute ISPRA estimated that the agro-waste production in Italy in 2018 was 324,370 tons and in 2019 was 311,001 tons [35] with a slight inflection of the total amount. In Italy, the evaluation of agricultural waste is affected by an uncertainty due to frequent illegal practices as abandonment in the environment, burning in field and collecting with the municipal waste. These reasons prevent a complete estimation of the real amount of agro-waste produced. As a consequence, the numbers above reported seem to be underestimated; perhaps they consider the tracked waste disposed with a fee. As a matter of fact, national production of special waste according to Decree n.152/2006 [34] implies that the subjects involved are obliged to declare the amount of waste produced, transported and recovered in the previous year. In 2018, the national production of all the special waste amounted to 143.5 million tons. Between 2017 and 2018, an increase of the total production was registered. In particular, an increase of 4.2 million tons of non-toxic waste (+3.3%) and of 376 thousand tons of toxic waste (+3.9%) was recorded. The Italian institute ISPRA estimated that just 2.2% of the waste originated from agriculture, hunting, fishing and food preparation can be considered hazardous.

The Italian institute ISPRA also defined the good practices adopted in the different regions by collecting them in a national database GELSO (GEstione Locale SOstenibile) [36]. The sustainable projects accepted in the database are selected by considering different criteria: environmental, social and economic sustainability. In Puglia, the districts of Bari and Lecce are involved in the field of renewable energy use. Bioenergy is considered the main source for the distribution of renewable energy in EU27 [37]. Solid biomass, biofuels, biogas and renewable municipal waste play a less role in electricity, however, they are fundamental in the heating plant and transport field. Currently, bioenergy plays a relevant role in Italy and is the most important sector in which the agro-waste are used. FAOSTAT (Food and Agriculture Organization of the United Nations) [38] reported that about 393 × 10^6 tons of agricultural residues were burnt on fields worldwide in 2017, contributing to the increase of environmental pollution. Of this quantity, it was estimated that 1.50 × 10^6 tons were burnt in Italy. In this country, marked differences between the regions actually exist [39], showcasing disparities in economic and technological development. The northern regions have a more industrialized vocation, while the southern regions are mainly agrarian. Southern Italy is generally considered to include eight regions: Abruzzo, Puglia, Basilicata, Calabria, Campania, Molise, Sardinia and Sicily. Despite the disparities occurring between South and North Italy, southern regions do not seem to be poor in terms of renewable energy. Meleddu and Pulina [40] affirmed that Southern Italy regions produced more renewable energy compared to the national average. No significant increase in the general production of special waste can be appreciated in Molise region from 2018 to 2019 (Figure 6). However, in Puglia, in the same period, a significant increase can be noted. Considering the annual regional incidence of special waste production on a national basis, it can be asserted that Puglia was responsible for the maximum incidence in the southern area.

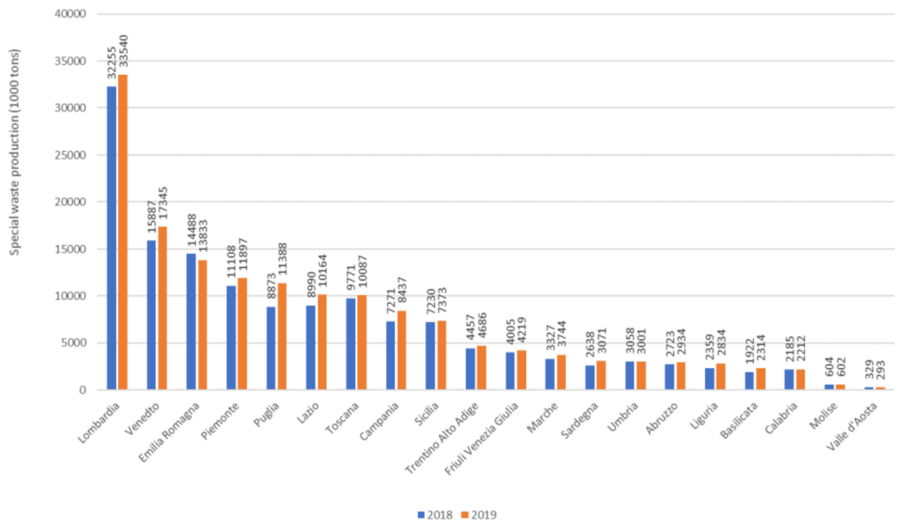

Figure 6. Total production of special waste at regional level from 2018 to 2019 (Source: Rapporto rifiuti speciali, ISPRA [35]).

The national Registry of Waste [32] (Figures 7 and 8) highlights that in Puglia, there is a significant contribution of the agriculture sector to the increase of non-hazardous residues. On the contrary, in Molise, the agriculture sector does not play a significant role on the production of non-hazardous residues. The data highlighted that, in general, Southern Italy plays an important role in the national production of agricultural residues, contributing with most of the pruning and pomace production of the whole country. These data further demonstrate that there is a great potentiality derived by the agricultural residues on the energy production. Even though technological or logistic limits might be an issue, a proper use of the available amounts of agro-waste in the Southern regions could be a great added value for the Italian energy production and for the sustainability of the environment.

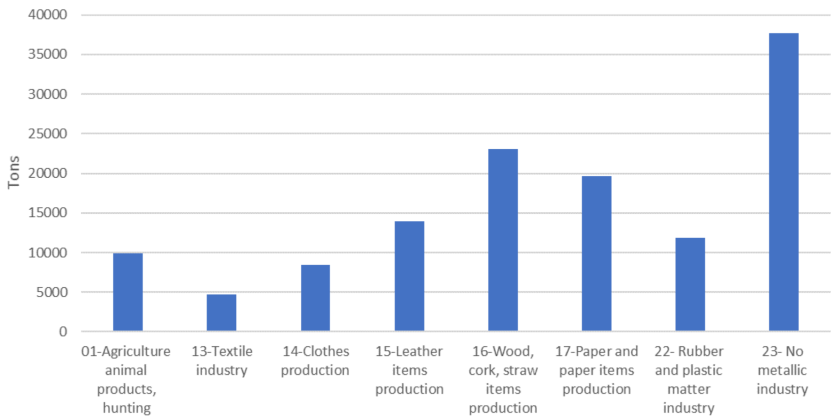

Figure 7. Non-hazardous waste production (tons) in Puglia considering different activities—2019 (Adapted from ISPRA [32]).

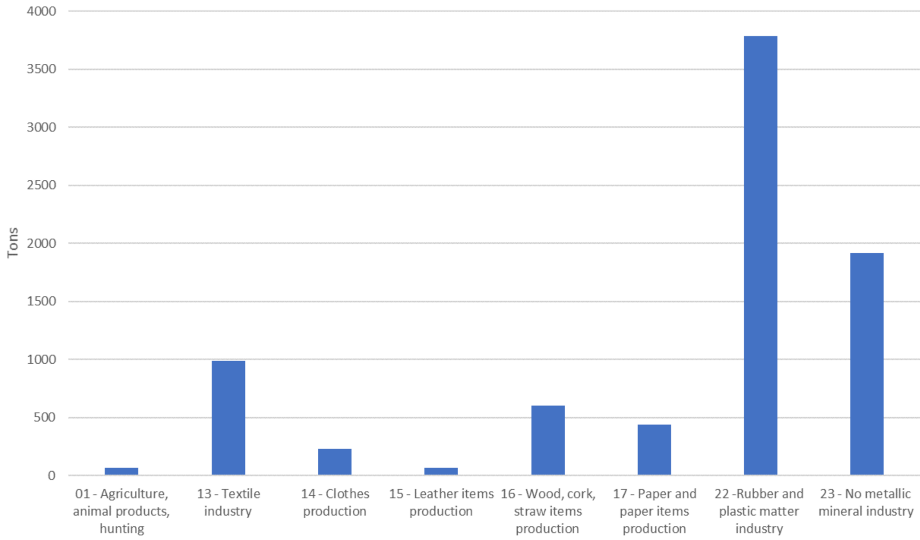

Figure 8. Non-hazardous waste production (tons) in Molise region considering different activities—2019 (Adapted from ISPRA [32]).

In general according to CORINE Land Cover 2000 (CLC2000) [41] cartography, it can be noted that Puglia has mainly an agricultural vocation, with a great concentration of vineyard, fruit trees and olive groves. On the other side, Molise shows a great concentration of broad-leaved forests and non-irrigated arable land. The most detailed analysis on the agro-waste production was provided by ENEA [42] which analyzed the biomass potential for different kinds of agricultural plantations considering the different regions.

Puglia has a total surface extension of 19,541 km^2. It is one of the regions with the largest number of used agricultural surface. The territory is mainly flat (53.3% of the total regional surface), 45.3% is hilly and just 1.5% is mountainous. Puglia is characterized by a great variety of plants, in relation to is morphological conformation, and it is also one of the poorest Italian regions in forest vegetation due to a long tradition of agricultural activities.

Figures 9 and 10 show the agricultural waste production in Puglia: straw and pruning have a great potentiality in terms of energy use. Spada and Dipaola [43] underline a non-homogenous framework: Foggia has the highest potentiality in terms of dry biomass availability due to most of the woodland vegetation (48.6% of the regional total); it is followed by the province of Taranto (25.5%), Bari (21.5%) and, finally, Lecce (2.6%) and Brindisi (1.8%).

Molise has a total surface of 4483 km^2. It is the second smallest region in Italy. The territory is mainly mountainous (55.3% of the total regional surface), while the remaining 44.7% is hilly. The agricultural sectors of main interest are crops (cereal) and zootechnics. Arable crops cover 72% of the total arable land. The remaining areas are cultivated mainly by food for livestock; permanent crops, instead, are destinated to olive and vine production. The graphs in Figures 11 and 12 show that the biomass involved in the energy sector mainly derives from fruit and straw, particularly in the province of Campobasso. Furthermore, there is a great production of pruning in the province of Campobasso, while fruit shell is limited.

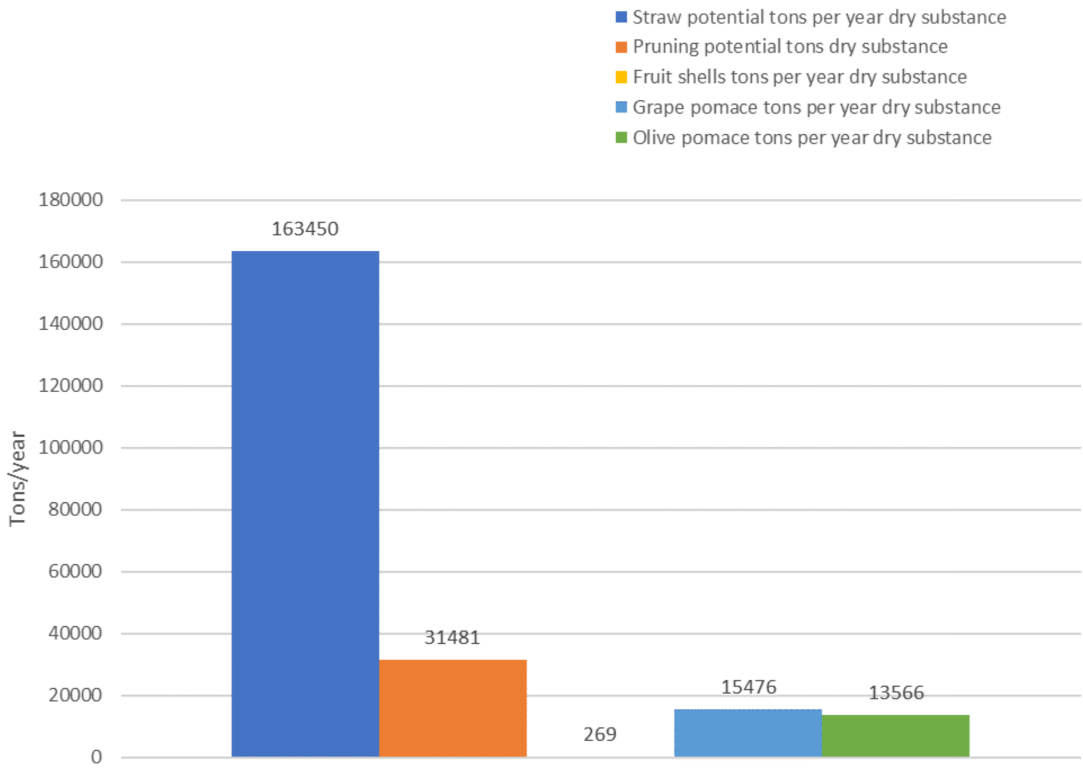

Figure 9. Biomass potential produced by different agro-waste in Puglia, dry fraction. (Adapted from Report RSE/2009/167 ENEA [42]).

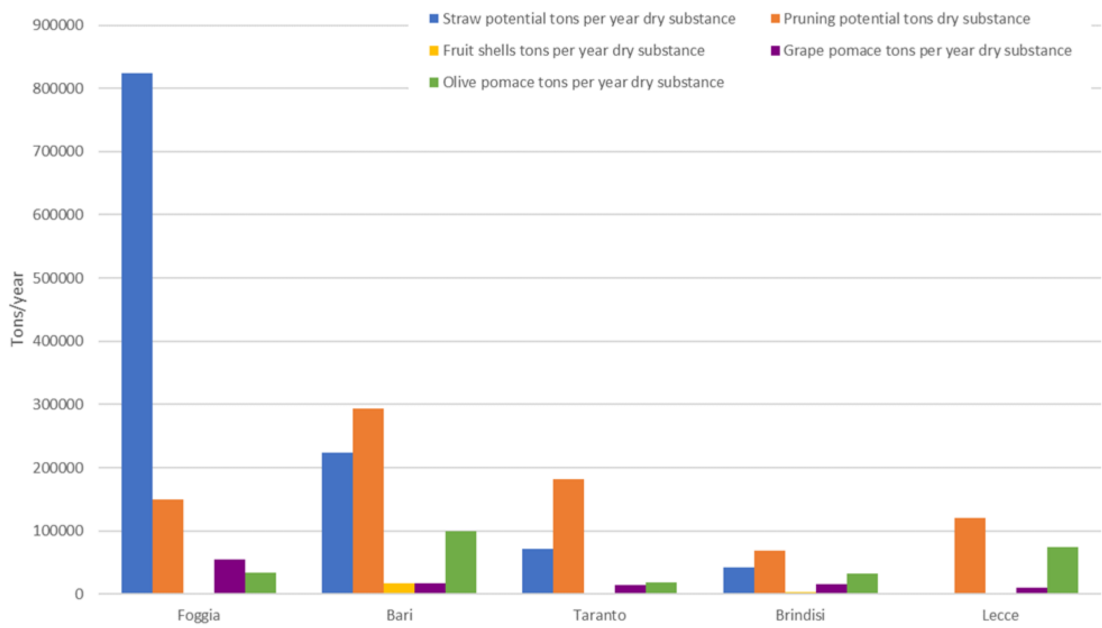

Figure 10. Biomass potential produced by different agro-waste in the main provinces in Puglia, dry fraction. (Adapted from Report RSE/2009/167 ENEA [42]).

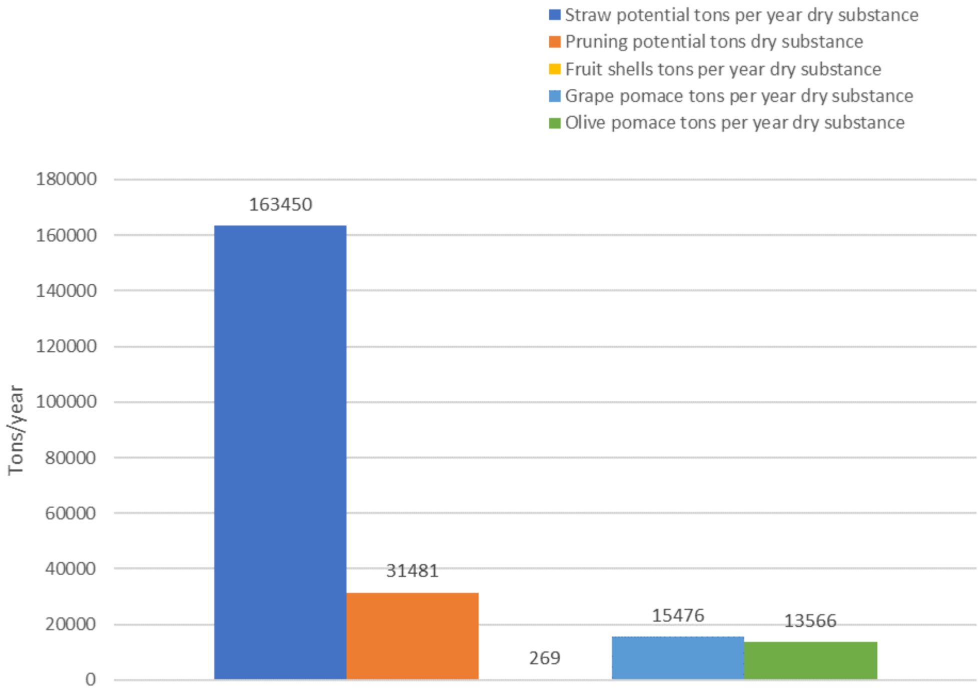

Figure 11. Total agro-waste production, dry fraction, in Molise. (Adapted from Report RSE/2009/167 ENEA [42]).

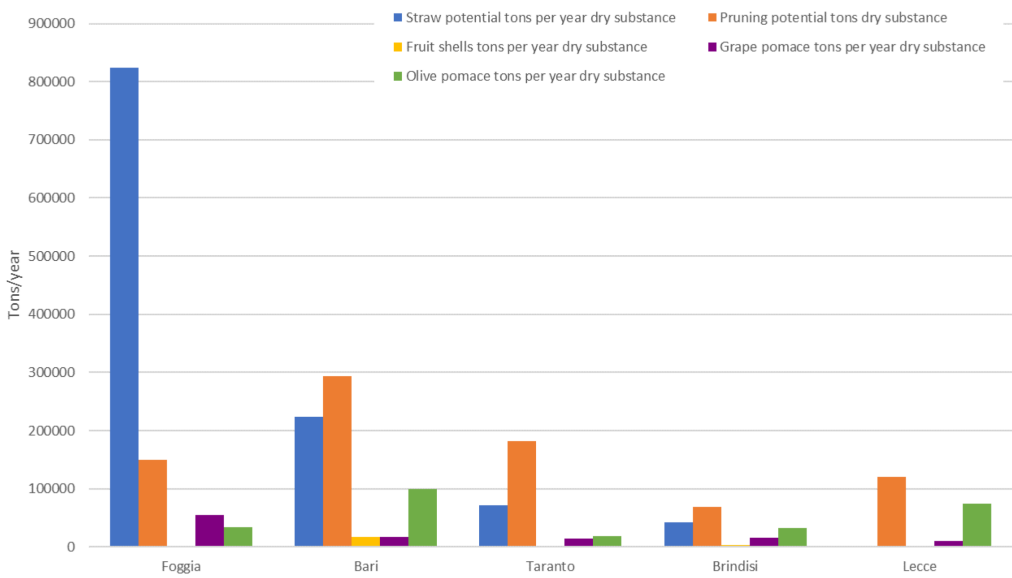

Figure 12. Biomass potential produced by different agro-waste in the main provinces in Molise region, dry fraction. (Adapted from Report RSE/2009/167 ENEA [42]).

With reference to the use of the recycled components in the building materials, in Italy, a National Decree named CAM (the minimum Environmental Criteria) has been recently issued [44]. It states the environmental requirements defined for the various phases of the purchasing process, aimed at identifying the best design solution, product, or service from an environmental point of view along the life cycle, considering market availability. Moreover, a national Protocol named ITACA was approved [45] as an evaluation instrument for the energy and environmental sustainability of the buildings. The ITACA Protocol is a multi-criteria system for the assessment of the environmental sustainability of buildings that leads to their classification through the attribution of a performance score. This Protocol was born from the need of the Italian regions to equip themselves with valid tools to support territorial policies and promote environmental sustainability in the building sector.

The Regional Law n.13/2008 [46] in Puglia promotes and encourages environmental sustainability and energy-saving both in territorial and urban transformations and in the building construction field.

In 2017, the Protocol "ITACA Puglia" was approved [47]. It consists of 39 criteria, each one regarding an environmental or energy aspect of the system building-plant and the site. The criteria are divided in 5 macro-areas: 1. quality of site; 2. resource consumption; 3. environmental load; 4. indoor environmental quality; 5. quality of the service. Furthermore, considering the energy performance as provided by the law, the method also takes into account the building-to-site relationship, water consumption, materials used, indoor quality and the preservation of performances in the time to come. An important link between ITACA protocol and the use of sustainable building materials is represented by the macro area no. 2 "resource consumption". As a matter of fact, the use of environmental-friendly materials constitutes one of the criteria of this macro area; it takes into account the possible, the use of recycled/recovered materials, materials from renewable resources, local materials, or renewable ones.

Although in Molise a regional ITACA Protocol does not yet exist, a regional law was approved in the framework of the national standards. The Regional Law n.30/2009 [48] has the aim to revitalize the building sector promoting green building techniques and the use of alternative and renewable energy sources.

5.2. Montenegro

According to MONSTAT [49], during 2019, in Montenegro, 1.276×10^6 tons of waste were generated. A comparison between 2018 and 2019 demonstrated that there was an increase of 1.2% in relation to the total amount generated (Figure 13). In particular, agriculture, forestry and fishery sectors are subjected to a decrease of 7.3%; sectors of manufacturing, mining and quarrying and other industries, a decrease of 0.7% and construction sector increases of 2.1%. In 2019, the amount of recycled components is 74.5% more in comparison with the previous year, due to increased recycling. There is a high potential of agricultural residues as biomass in Montenegro. Curovic et al. [50] have estimated that approximately 9490 tons of dry matter of agricultural residue are available. However, currently, there is no use for it as an energy purpose or as raw matter for sustainable building materials.

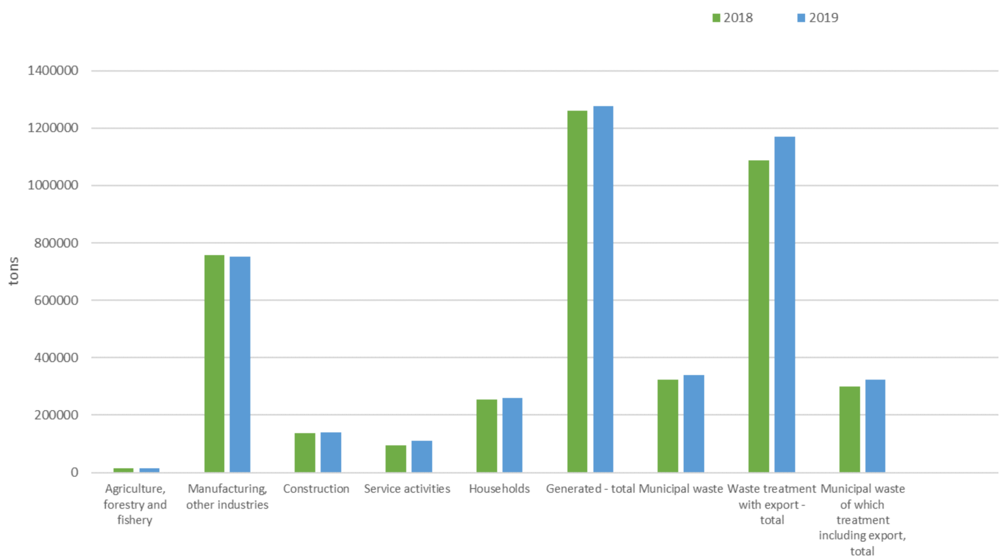

Figure 13. Generated and treated amounts of waste, 2018 and 2019, in Montenegro. (Adapted from MONSTAT [51]).

Considering the non-hazardous waste, there was a decrease of the production of waste originated from agriculture, forestry and fishing sectors. A slight increase was instead observed about the production of hazardous waste from 2018 to 2019 (Figure 14).

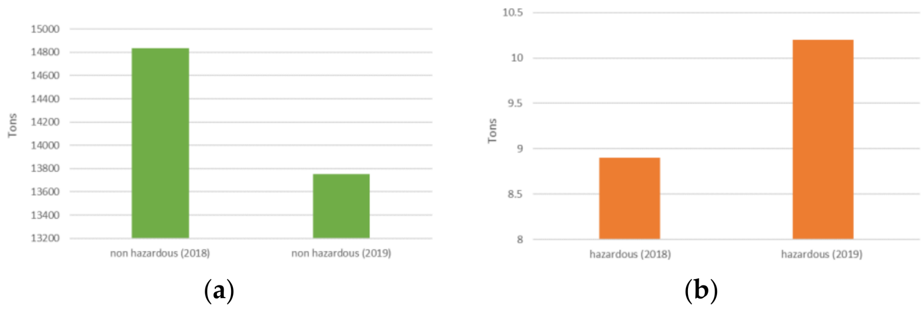

Figure 14. Generated amounts of non-hazardous waste (**a**) and hazardous waste (**b**) by agriculture, forestry and fishery sectors. (Adapted from MONSTAT [51]).

According to the data by MONSTAT [49,51], the utilized agricultural land in 2019 is 257,469 ha that underlines an increase of 0.3% compared to 2018. In total, utilized agricultural land areas, perennial meadows and pasture areas involve 94.3%, while arable land expands for 2.8%, permanent crops for 2.1% and kitchen gardens for 0.8%. In comparison with 2018, perennial meadows and pasture areas increase by 0.2%, arable land by 0.1% and permanent crops by 1.0%. On the contrary, kitchen garden decreased by 0.2%. Total production of potato in 2019 rose by 1.6% compared with the previous year. An increase in production was also achieved for oats (7.4%), maize of grain (1.1%), dry beans (7.8%) and melon (2.4%). Compared to the previous year, the total production of olives underwent a rise, while production of plums, apples, pears, peaches, mandarins and grapes decreased.

The Montenegrin agriculture considers traditional production, extensive methods of production and fragmented holdings with an average size of 5 ha [51]. The exact estimation of the quantities of agricultural waste currently used for energy production depends on the availability of each crop. Year to year, the total amount of residue is strictly correlated to several aspects as follows:

- the harvesting method;
- the moisture content;
- the demand of agricultural residues for other scopes (animal feeding or bedding);
- the need to store the residues on the soil as nutrients.

The main crops generating considerable amounts of by-product are potato, maize, wheat, rye and barley. The main arboriculture residue resources available in Montenegro are vineyards, olives, apples, plums, pears and citrus fruits' pruning. Vineyards' pruning are the most significant source of biomass. It can be assessed as one of the major contributor of the residues.

Due to the outdated technology and lack of systematic collecting, thermal energy use of biomass residues such as pruning does not constitute a consolidated technique in Montenegro.

Of the total arboriculture amount, the olive production is 19% while the vineyards are 58%. These wastes can represent one of the most important factors for obtaining biomass suitable for an energy purpose or as new raw matter for sustainable products. Unfortunately, the use of olive residues is only 50%. Approximately, 80% of the olive production contains elements suitable for new uses: vegetable water, pulp and stones from the olives, and the hard part of the olive has a high heating value.

Glavonjic [52] underlined that the overall potential of timber biomass residue from vineyards and orchards is 2482 tons per year. The overall potential of agricultural biomass residue is 8154 tons per year.

The use of livestock residues represents another opportunity for energy production through anaerobic digestion process. The biomass derived from the livestock residues is mainly used for energy purposes: biogas and methyl-ester production from bio-oils.

Although, currently, the agricultural residues are not used in building components and there are not companies involved in the re-use of agro-waste, the country is equipped with an Energy Policy Plan until 2030 [53]. This is the main strategic document in the energy field decreeing three main priorities and twenty key strategic objectives.

As a consequence, different decrees were released in terms of energy-saving applied to buildings. The Law n.057/14 [54] introduced requirements of sustainable buildings, specifying them in specific subsequent rulebooks.

5.3. Albania

Lushaj et al. [55] stated that the UN Economic Commission for Europe considers scarce the state of waste management in Albania; the waste collection systems work well only in cities. The disparity is caused by the inability of national, regional and local governments to adopt an efficient sustainable waste collection strategy even if the legal framework is in accordance with European Union Acquis Communautaire [56]. No official data are available about the waste generated by agriculture, forestry and fishery sectors.

According to INSTAT [57] 1.08 $\times$ 10^6 tons of urban waste were managed, marking a decrease by 18%, compared to 2018 (Figure 15). The annual national amount of urban waste per capita, in 2019, amounts to 381 kg/capita comparing to 462 kg/capita in 2018.

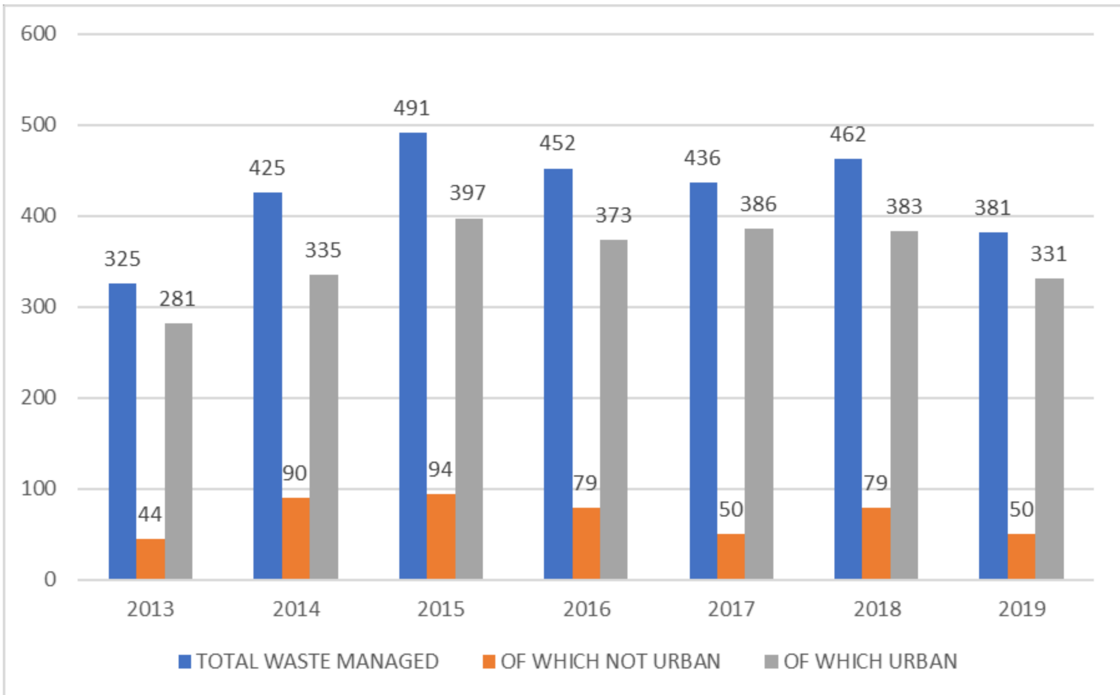

Figure 15. Total urban waste managed by generating resources (kg/capita). (Adapted from INSTAT [57]).

Oncioiu et al. [58] stated that the increase of agricultural production in Albania led to the production of a great amount of residues that potentially can be used for energy production. On the contrary, the current use of agricultural residues is limited.

The statistical data highlights that there is an increasing annual trend of fruit trees, grape and citrus production in Albania with an approximate amount of 15,000 tons/year for fruit tree, 4000 tons/year for grape and 3000 tons/year for citrus [59].

The prediction of production trends in Albania are based on actual production trends, available surface areas, the technology of plant production and the potential increase of plant production. The stone fruits (as plum, cherry and peach) are prevalent in comparison with other types of fruit in Albania. The use of the residues derived from stone fruits is strictly connected to the potential use for energy production. The processing of grapes in Albania increases from 50 to 70%.

Brahushi et al. [60] predicted that the amounts of the processed fruit in the year 2020 will reach up to 75,000 tons (corresponding to 25% of overall production), and in the year 2025, will be about 130,000 tons (or 35% of production). The authors stated that the residues produced by fruit trees, citrus and grape biomass, including the fruit pomace are suitable for bio-energy production. Furthermore, pellets' production from fruit and grape processing waste represents a great opportunity for sustainable energy production. Thus, it is possible to underline that in Albania, there is a potential of using the waste derived from the manufacturing of fruits, vegetables, citrus and grapes, due to the increasing trend registered yearly.

According to INSTAT [57], the vegetable production in 2020 was 1.295×10^6 tons, increasing by 2.99%, compared with the year 2019. The highest level of vegetable production was achieved in the prefectures of Fier with 503,531 tons, Berat with 131,735 tons and Tirana with 130,001 tons.

Fruit tree production in 2020 was 274,749 tons. The highest level of production was reached in the prefecture of Korça with 82,007 tons, followed by the prefectures of Elbasan with 38,470 tons and Fier with 33,829 tons. Pome fruit groups represent 44.41% of the total production represented by apples with 84.03%. Korça prefecture occupies 83.14% of total apple production in the country. The production of permanent crops concerns the production of fruit trees, olives, citrus and grapes. In the fruit group, the largest amount refers to plums with 47.55%, followed by peaches with 23.25% and cherries with 23.34%. In 2020, 131,971 tons of olives were produced, increasing by 34.24% compared to the previous year. The highest level of olive production was registered in the prefecture of Fier with 35,854 tons, followed by Berat with 33,082 tons and Elbasan with 22,764 tons. Olive varieties amount to 82.22% of total olive production. The citrus production in year 2020 increases by 4.95% compared with 2019. In 2020, grape production was 199,070 tons, increasing by 4.83% compared with the previous year. Brahushi et al. [59] presented data of fruit tree, citrus and grape productions from year 2000 to 2015 (Figure 16).

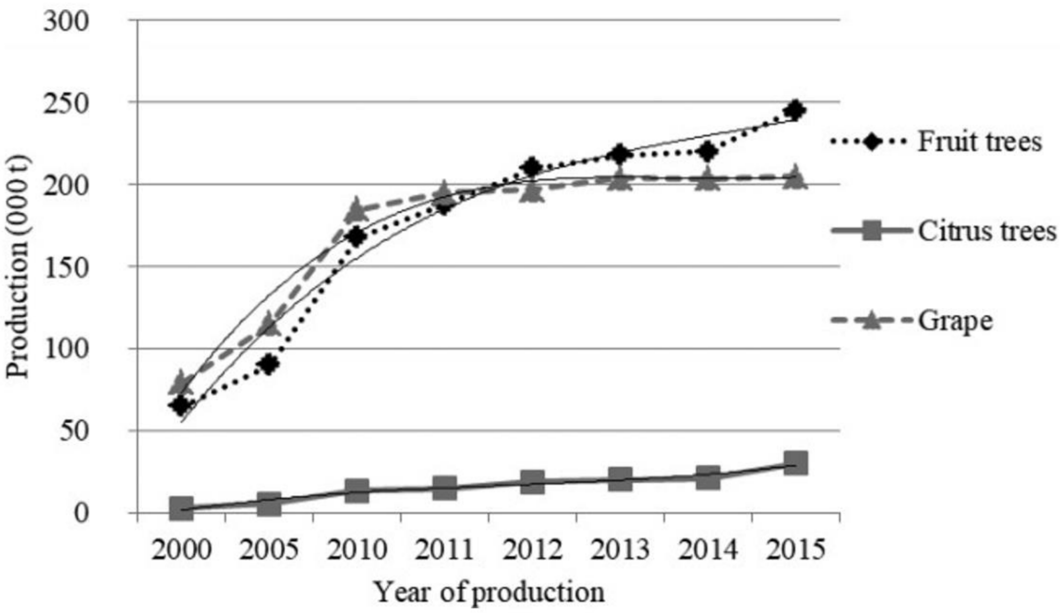

Figure 16. The trend of fruit tree, grape and citrus production in Albania. (Source: Brahushi et al. [59]).

The authors used a polynomial model of third order for the prediction of the production trend until 2020 and 2025. Thus, the results achieved show that the production of fruit trees, grape and citrus in 2025 will be about 370,000 tons/year for fruit trees, 240,000 tons/year for grape and 56,000 tons/year for citrus. This demonstrates that the residues produced by these kinds of trees will constitute a significant amount of new potential raw matter for the next year.

Construction is one of the most developed sectors in Albania nowadays. In the last years, a lot of new tower buildings for residential and businesses are constructed everywhere.

In Albania, most of the agricultural by-products are burnt on field. There are no strategies from the national and local institutions on how to use agro-waste in different ways.

In terms of energy-saving, the Law n.124/2015 [60] promotes national policies regulating the possible strategies to increase the security and sustainability of energy supply and to serve as a regulator of the energy market in the country. Furthermore, Law n.116/2016 [61] has the purpose to create the legal framework for improving the energy performance of buildings, considering local climatic conditions, indoor comfort conditions of buildings and is cost-effective. However, no specific standards applied to the buildings yet exist, thus, European NZEB (Nearly Zero Energy Buildings) standards are considered on a voluntary basis when designing a sustainable building.

6. Discussion and Conclusions

The use of agro-waste, a subset of the much larger biomass production, is growing across the world. In Europe, the biomass is mostly used as pellet, chip form or burnt, converting it into thermal energy. Starting from the consideration that agricultural residues can represent new opportunities for the current challenges of the circular economy, the present study provided a snapshot of the biomass available in four regions of EUSAIR (Puglia, Molise, Montenegro and Albania), suitable to be used as new raw matter for building components.

The analysis performed has highlighted that in Italy, the agricultural by-products are considered "special waste", thus, their re-use as new matter can contribute to cut down the disposal costs, currently supported by the agricultural companies. Some legislative decrees regulate the disposal of the agro-waste. Bioenergy, biofuels and biogas are currently the alternative strategies most used to recycle the biomass.

In Italy, the northern regions have a more industrialized vocation, while the southern regions are mainly agrarian. Molise and Puglia belong to southern Italy. Southern regions seems to be efficient in terms of renewable energy. In fact, Meleddu and Pulina [40] proved that Southern Italy regions produced more renewable energy using agro-waste residues comparing to the national average. In Montenegro and Albania, research studies and statistical data taken from the national institutes demonstrated that, despite the great production of agro-waste residues derived from arboriculture of olive and vineyards, no political strategy exists in terms of re-use and recycle of residues. Therefore, in these countries, agro-waste may have a potential impact for the sustainable development, playing a strategic role toward the transition to a circular economy approach. In light of this, considering that the building sector is forced by current international decrees and standards to use more sustainable materials for building applications for the energy-saving and by-product recycling, the bio-based materials obtained from agro-waste can represent a precious strategy to avoid and challenge the fossil carbon use. The present work has shown that several researchers dealing with the use of biomass for building materials were carried out. Different applications were implemented by testing hygrothermal, physical and acoustic performances: panels, blocks, multi-layer solutions, mortars and plasters. The results achieved underlined that the bio-based materials are able to achieve great performances similarly to traditional materials currently existing on the market.

As a consequence, reusability, recyclability and recoverability can be considered the key points of a green economy. In this sense, due to the gap currently existing between academic research and the industrial sector, a close collaboration among researchers, local governments and industrial stakeholders can provoke the growth of the local economy at the same pace as the development of new research lines about sustainable building materials.

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