Livestock Wastes Sustainable Use and Management: Assessment of Raw Sheep Wool Reuse and Valorization

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Abstract: Worldwide, around 998 million tons of agricultural waste are generated yearly, including livestock wastes, which create several critical environmental issues if not properly treated. In this study, a Geographical Information System (GIS)-based model to locate and quantify both the yearly amount of livestock waste, i.e., sheep wool, and the territorial distribution of sheep farms, was carried out and applied within the selected study area. The aim was to identify those territorial areas most suitable for localizing new shared wool collection centers to sustainably manage the reuse of this waste as potential green building material. Data related to both sheep farms and sheep number and the related sheep shared wool (SSW) yearly production were acquired and applied in GIS. By GIS-based model results, two collection centers have been identified within the provinces of Agrigento and Enna. Then, to develop a sustainable reuse in terms of reducing environmental impact due to the SSW logistics and supply phase, a possible third collection center was localized within the territorial area belonging to the province of Ragusa (south area of the Sicily). In this research, for the first time the issue above reported was addressed, by achieving results that contribute at developing an efficient collection chain for recovering and properly reusing SSW to respond adequately to a further industrial scale production.

Keywords: circular economy; livestock waste; GIS; sheep wool; spatial analysis; environmental impact; sustainability

1. Introduction

Worldwide, the volume of waste yearly generated ranges from 7 to 10 billion tons [1]. By 2050, the annual production of world waste, coming from households, agriculture, commerce, industry, and construction activities, it is expected to be 27 billion tons per year [2]. For this reason, one of the most important global environmental issues is related to the management and disposal of these wastes. The mismanagement of these huge volume of wastes causes air pollution, water, and soil contamination, with serious consequences for the healthy life of our planet. A first effort must be made to minimize waste production and, in the case that its generation cannot be avoided, the second option is the valorization of these wastes. Wastes recovery, reuse, and recycling in order to obtain new suitable products, materials, and energy is the action for a sustainable global development. The reuse of wastes is of relevant importance within the circular economy framework, one of the main blocks of the European Green Deal [3]. As known, in many cases, a large part of waste is not properly managed and valorized, especially in developing countries [4].

The worldwide growth of agricultural production, often accompanied by the development of the intensive farming system, resulted in a significant increase in agricultural wastes (AW). It is estimated that approximately 998 million tons of agricultural waste are produced each year in the world [5]. Agricultural wastes, co- and by-products are all the residues resultant from agricultural activities, including cultivations, livestock productions, and aquaculture. They can be liquids, slurries, or solids, and their composition varies depending

on the type of agricultural activity from which they are generated. The conversion of wastes into new raw materials is a priority for policy makers, and the agricultural wastes (AW) can have an interesting role because if valorized and properly managed can be switched into a resource for new production cycles [6]. A correct disposal of management and a potential conversion in new raw materials of agricultural waste could reduce pollution and cost production, in accordance with circular economy framework [7,8]. The significant amount of AW represents a serious issue for environmental pollution and landscape quality, especially in rural areas, with a toxicity potential to air, water, plants, animals, and humans (e.g., AW coming from cultivation are often affected by a high amount of chemical fertilizer, AW deriving from livestock production present a high bacterial load). Several economic benefits could be obtained through the valorization of agricultural by-products, such as reducing production costs and increasing the economic benefit of farming, by achieving new performant products, creating jobs, and minimizing the disposal of by-products into the environment [9]. Agricultural wastes need to be considered as potential resources and not undesirable and unwanted residues discharged to the environment.

A properly AW utilization is based on five different phases related to collection, storage, treatment, transfer, and utilization. All these phases require new technology, attitudes, incentives, new dedicated policies and substantially a new approach to agricultural wastes management with the aim to both obtain a reusable waste product and reduce the reintroducing of a non- reusable waste product into the environment [7].

On the other hand, the construction sector, with 50% of carbon dioxide emissions, up to 50% of energy and natural resource consumption, and with 50% of solid waste production, is considered also to be the main cause of environmental degradation, of global warming and climate change [10].

Sustainability and energy efficiency of buildings are based on thermal insulation improvement, on energy and CO_2 emissions reduction, and on the use of alternative eco-friendly materials, that are contemporary recyclables, renewables with a low footprint impact. All these factors together could contribute to achieve a sustainable building sector.

Fully complying with eco-friendly construction criteria and environmental certifications (e.g., BREEAM, LEED, DGNB, and Green Mark), a sustainable construction is a construction that is realized by using renewable and recyclable materials when built, and contemporary is reducing energy consumption and waste production. Furthermore, the building design should foresee components that have a continuous positive effect on the building's environmental impact during its operating-life.

These mean an adequate insulation to prevent heat loss, the use of renewable source of energy (i.e., solar panels) to reduce energy consumption, and the use of building materials with a low footprint and an extended lifecycle.

Several studies focused on the use of renewable resources and sustainable materials that could be integrated into construction processes, by replacing those traditionally employees, e.g., plastic components [11,12].

Among livestock waste, sheep wool thanks to its mechanical and physical behaviors, is gaining attention in the building sector [13]. Wool fully complies with the principles of eco-sustainable construction; it is suitable for thermal and acoustic building insulation, it can absorb water vapor up to 33% of its weight without appearing humid and contemporary it rejects water in liquid form, this physical feature is favoring a natural indoor regulation of humidity by reducing the risk of condensation.

Moreover, sheep wool through a chemical process (i.e., chemisorption) neutralizes harmful and odorous substances such as nitrogen dioxide, sulphur dioxide, toluene, and formaldehydes [14], it is self-extinguishing, and in the event of a fire it does not burn but melts [15]. Sheep wool fibers could also be used as additives in bio composite materials to improve their mechanical behaviors, as ductility and shrinkage rate [16].

On the contrary, despite its features, wool is considered a solid waste that implies a problem of increasing concern for the complex and difficulty disposal management.

Recently, sheep shearing activity exclusively represents a cost for the farmer, about €1.80/sheep, that is necessary for the animal welfare.

Globally, sheep are the most widespread animal species, with 4000 different breeds and a number of heads that is around 1.2 billion. Raw wool production could be only evaluated on a base of sheep number. In this regard, Pulido et al. [17] estimated a European wool production of about 260,000 tons in 2011.

At European level, wool waste management is regulated by EC Regulation 1069 (2009), and EU Regulation 142 (2011). According to these regulations wool is classified as category 3 of animal by-products (ABPs), that means low-risk waste. These regulations foresee specific procedures for handling, treating and disposal, and transportation for categories 3 ABPs. Raw wool, if not washed or disinfected, cannot be buried or burned without a permit, and must be disposed as quickly as possible by incineration or landfilling specialized sites. According to these European regulations breeders are required to quickly dispose wool, and since a quick wool disposal sometimes is difficult to reach, illegal practices of storage, transportation and disposal are made. Zoccola et al. [18] affirmed that these illegal practices represent the reason why it is difficult to evaluate the real amount of waste wool disposed in Europe.

The advantages deriving from an unconventional possible use of wool waste as natural, renewable, and biodegradable fiber in building sector, also concerns a strong reduction of CO_2 emissions and environmental pollution.

However, the real reusing of raw wool is not widespread and is strongly characterized by improper waste management. A sustainable reuse process of wastes or by-products is always started by accurate disposal management by assessing their production and localization.

In the study by Florea [19], the realization of new sheep wool collection centers with the aim to provide solutions for the capitalization of sheep wool within Romania, by reducing avoiding waste, was reported. A deeply statistical analysis has been carried out concerning the evolution of sheep flocks in the country of Romania over the past two centuries, and policy considerations were made. However, the methodology applied to optimize the location of existing collection centers and the establishment of a new one is based only on the amount of wool available considering a maximum distance of 100 km to the center and is not clearly explained.

In this paper, for the first time a GIS-based tailored methodology was put forward in order to locate the territorial areas with the highest concentration of raw wool in a selected study area. Therefore, mechanical results obtained from authors in a previous study concerning the possibility of the use of greasy wool in the building sector encouraged this research [16].

Based on acquired and analyzed data, the main objective was to identify the geographical areas most suitable for the positioning of future shared wool collection centers, by taking into account both the farms number, their territorial distribution, and the number of sheep and related wool production. Shared wool collection centers represent an opportunity for reducing environmental impacts due to all the logistic, transport and supply phases concerning the recovery of this livestock waste.

2. Materials and Methods

2.1. Wool

Sheep wool is a natural fiber deriving by the shear activity of the fleece of sheep; the main components of sheep wool are keratin protein fibers (60%), followed by the 15% of moisture, 10% fat, 10% sheep sweat and 5% impurities. Table 1 shows the usual chemical composition of wool [13].

Table 1. Chemical composition of raw sheep wool [13].

Keratin	33%	Carbon	50%
		Hydrogen	12%
		Oxygen	10%
		Nitrogen	25%
		Sulphur	3%
Dirt	26%		
Suint	28%		
Fat	12%		
Mineral water	1%		

The possible alternative uses of this livestock waste in building sector represent the man topic of several researchers found in literature [8,16].

Among natural fibers, thanks to its peculiar chemical and physical behaviors, sheep wool is suitable for the control of microclimatic conditions inside buildings [20,21]. The insulation indoor air quality (IAQ) and human and/or animal wellness could be improved by using sheep wool as insulation materials. Wool is able to neutralize toxic substances, e.g., nitrogen dioxide, sulphur dioxide, toluene, and formaldehydes, thanks to a chemical process (i.e., chemisorption). In the past, sheep wool thermal and acoustical behaviors have been compared with other common insulation materials, i.e., polystyrene foam and glass wool [20]. Obtained results were similar for all three kinds of investigated materials, only a significant decrease was detected regarding the embodied energy of sheep wool, that is, the energy used for the production and transportation of material. Another potential use of this fiber is as reinforcement fiber for composites materials [22,23].

Sheep wool used in this work, unsuitable for textile industry and deriving by dairy sheep with a low-quality fleece, was physically and mechanically characterized by authors in a previous study [16]; the aim was to assess the possible use of this agricultural special waste as a strengthening system for raw earth building elements. The average tensile strength obtained was 137.31 MPa, and the 42.00% the rate of elongation at break. These values supported the hypothesis of using sheep wool fibers as reinforcing material, and by comparing the values with those found in the literature, it was found that the tensile strength ranged between 120 and 174 MPa, and elongation at break from 25 to 35% [24].

Table 2 compares the mechanical behaviors of sheep wool fibers with other natural fibers, in particularly vegetable fibers, commonly used as reinforcement fibers for bio composite materials [25,26].

Table 2. Mechanical properties of some common vegetable fibers, re-elaborated from Parlato et al. [16].

Fiber	Tensile Strength [MPa]	Elongation at Break [%]
Wool	137.31	45–50
Jute	325–770	2.5
Flax	700–1000	2.3
Hemp	530–1110	3.0
Ramie	915	3.7
Bamboo	575	2.0
Banana	721.5–910	2.0
Henequen	500	4.8
Pineapple	1020–1600	0.8
Kenaf	745–930	1.6
Coir	140.5–175	27.5
Sisal	460–855	8.0
Abaca	410–810	3.4
Cotton	250–500	7.0
Isora	550	5.5

It appears evident wool exhibits a lower tensile strength, but on the contrary, the elongation at break is higher than the most commonly natural fibers used as reinforcement material [27]. This aspect improves ductility of the composite [28].

2.2. Study Area

Sicily is a region of southern Italy with a territory shared between 9 different provinces: Palermo, Catania, Messina, Trapani, Ragusa, Agrigento, Caltanissetta, Enna, and Syracuse. Sicily is both the largest Italian region (25,707 km^2) and the largest Mediterranean island, surrounded by the Tyrrhenian Sea to the North, the Ionian Sea to the East and the Mediterranean on the remaining coasts (Figure 1).
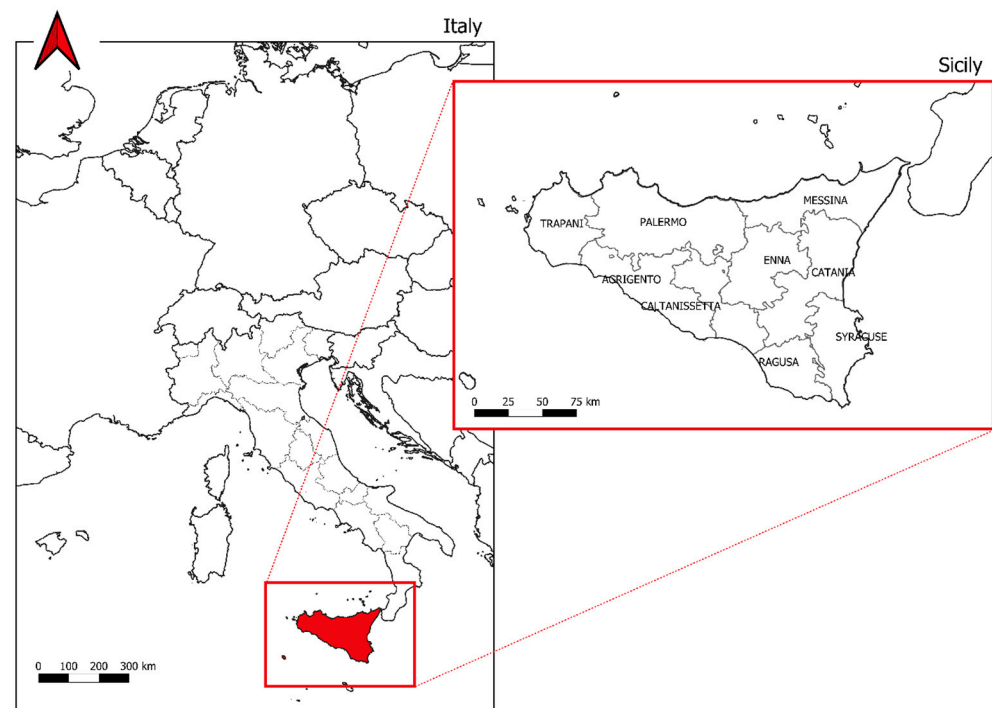

Figure 1. Study area geographic position.

In Italy, Sardinia and Sicily are the regions with the highest number of sheep, 3,039,160 and 737,819, respectively. Sicily is characterized by the dairy sheep breeder activity; dairy sheep are animals with a low-quality fleece totally unsuitable for textile industry. For this reason, this southern area of Italy is strongly penalized by a yearly high production of this livestock waste, i.e., raw wool, and the problem of its disposal is potentially relevant. In Table 3 are reported the Italian sheep consistency at region level.

Table 3. Consistency of the Italian sheep population divided by region. (Source processing IZS—December 2020).

Italian Regions	Number of Sheep
Sardinia	3,039,160
Sicily	737,819
Lazio	580,322
Tuscany	321,534
Calabria	211,270
Apulia	205,632
Basilicata	183,828
Campania	177,960
Abruzzo	158,582

Table 3. *Cont.*

Italian Regions	Number of Sheep
Marche	119,764
Piedmont	119,357
Lombardy	114,963
Umbria	95,365
Trentino Alto Adige	74,458
Veneto	69,424
Molise	55,977
Emilia Romagna	50,827
Liguria	9945
Aosta Valley	1904
Total	6,346,310

Moreover, nowadays in Sicily, there does not yet exist any recovery action of this special waste that could be considered the first step for its correct disposal management and possible reuse.

2.3. Data Analysis

In this study, by evaluating data provided by National Zootechnical Registry (average 2017–2020) of the Italian Ministry of Health (IZS), an extensive database was implemented with the aim to quantify and localize both the sheep farms, and the yearly sheep wool production, within the study area. To obtain information about the geographical areas where the production of this livestock waste is high, a Geographical Information System (GIS)-based model was put forward and applied. GIS is a suitable decision support tool to take in, to arrange, to examine, and to localize geographical data. The GIS-based model results were elaborated and assessed with the aim to localize the most suitable areas for localizing one, or more, collection centers of shared sheep wool; the final purpose was to minimize the environmental impact related to the logistics and supply phases for the storage of this livestock waste. Within the GIS software, i.e., the open-source QGIS software (ver. 3.10.11), the Regional Technical Maps (RTM 2008) was used as base map to carry out both thematic maps and heatmaps. By analyzing available data on IZS, the municipalities with the greatest number of sheep farms, the provinces with the highest surface areas dedicated to sheep wool breeding and consequently with the maximum amount of yearly shared wool production, were identified and localized on GIS software. QGIS software was used to perform all the GIS analyses; several maps, both thematic and heatmaps, were carried out by combining data both supplied by the base maps and coming from the database. Firstly, data from National Zootechnical Registry (December 2017–2020) were used for analyzing data related to livestock farming in the study area.

In detail the steps listed below were followed:

1. Data preparation for GIS-based analyses (National Zootechnical Registry (December 2017–2020)).
2. GIS-based analyses for carrying out the maps.
3. Quantification and location of the heads sheep and the related yearly wool production (SWF) at provincial level (thematic maps).
4. Localization of sheep farms at municipal level (thematic maps).
5. Heatmaps of sheep farms at municipal level and sheep number at provincial level.
6. Weighted Heatmap elaborated by a computational analysis overlapping data concerning farms and sheep wool amount, by applying Heatmap plugin available in QGIS software.
7. Identification of two suitable areas for localizing wool collection centers and a possible third area for an additional one.

In detail, the flow chart of the methodology including a full description of the steps, inputs, intermediate outputs and results is reported in Figure 2.
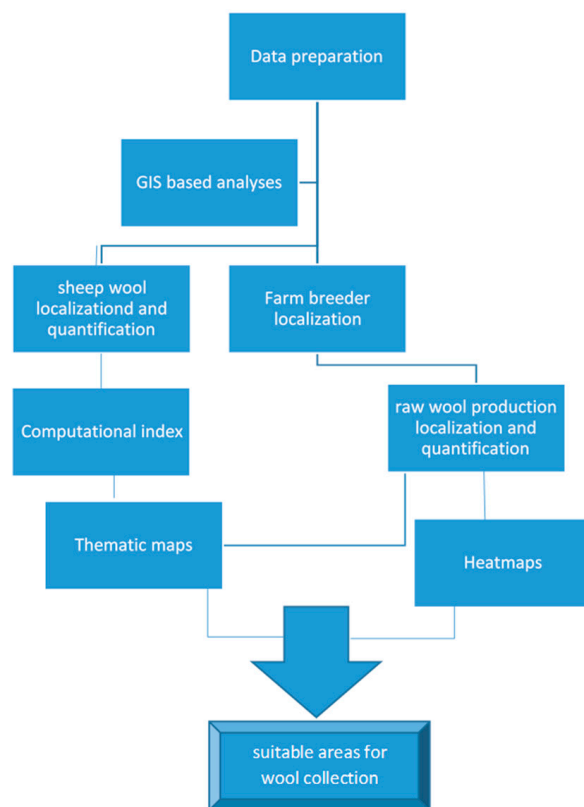
Figure 2. Methodology flow chart.

　　GIS-based model used data concerning sheep number, and farms were selected and analyzed to identify both the areas most occupied by both farms and sheep number.

　　Then, by using the spatial analysis GIS tool, the acquired data were elaborated and applied for providing distribution of both sheep number and farms localization. A tailored methodology was developed to quantify the yearly SSW production within the study area.

　　The next step of the methodology was the computation of the index (SW_i) for describing the amount of sheep wool production by applying the following equation:

$$SW_i = 1.5 \, n \, S \, [\text{kg}] \tag{1}$$

where:

　　SW_i represents the total amount of shared wool, which correspond to 1.5 kg of wool for each shared sheep.

　　The average yearly production of shared wool is 2.2 kg for rams and of 1.5 kg for the ewe. These values found in literature [29] were also checked by authors. During the month of May 2021, the average wool production of the "*Valle del Belice*" sheep breed, and coming from a farm located in Pachino, within the province of Syracuse, was estimated. The amount of raw wool of each animal was weighted (Figure 3). Then, the total of the weighted wool was divided for the number of sheep present in the farm, and the average of 1.5 kg/sheep was obtained.

　　By classifying the Sicilian provinces through the application of Jenks tool plug-in, available in QGIS software, a territorial distribution of the production areas was obtained, with the aim of maximizing the differences among the classes. Furthermore, collected data were reported and elaborated in order to estimate territorial areas highly characterized by both farms' concentration and number of sheep. Then, with the aim of assessing, within each province, those areas characterized by the highest density of SSW, firstly the Polygon centroids plugin was applied, then, the obtained base map was used for carrying out the Heatmap based on the amount of available SSW. Furthermore, during the application of

the Heatmap plugin, the discrete-interpolation method was set, and the input feature was weighted by the attribute related to the wool availability.

Figure 3. Example of weight activity of sheared wool.

Finally, data related to farms localization, and the wool production of sheep wool, were computed together.

A weighted heatmap was elaborated by using the computed index (I_{scc}) as reported below:

$$I_{scc} = nf x1 + 0.8\ ns \tag{2}$$

where:

I_{scc} is the index computed to carry out the weighted heatmap;

nf is the number of farms;

ns is the number of sheep.

The weighted heatmap was put forward because data related data farms and sheep number are not always in accordance; in this regard, this computed index arises to the need of minimizing transport and logistical processes. In detail, for these analyses the Polygons centroids plugin was applied before carrying out the heatmap.

From the obtained weighted heatmap, it was possible to define and select the most suitable areas for localizing the future collection centers by reducing environmental impact due to the logistic and supply phase.

3. Results and Discussion

Data concerning farms breeder, sheep, and the related wool production, were obtained by elaborating and analyzing data acquired by IZS database.

To obtain the distribution of breeder and number of sheep at territorial level, all collected data were organized, elaborated, and applied by implementing a GIS-based model and developing base maps.

Firstly, by using Jenks tool, a thematic map showing the distribution of territorial areas dedicated to sheep breeding at provincial level was carried out (Figure 4). The Sicilian provinces were grouped in three different classes based on their number of sheep. Palermo, followed by Agrigento and Enna are the provinces with the highest number of sheep. On the other hand, Syracuse and Ragusa resulted as the provinces with the lowest number of

sheep, probably due to their high extension of protected crops and few free surfaces for breeding activities [30].
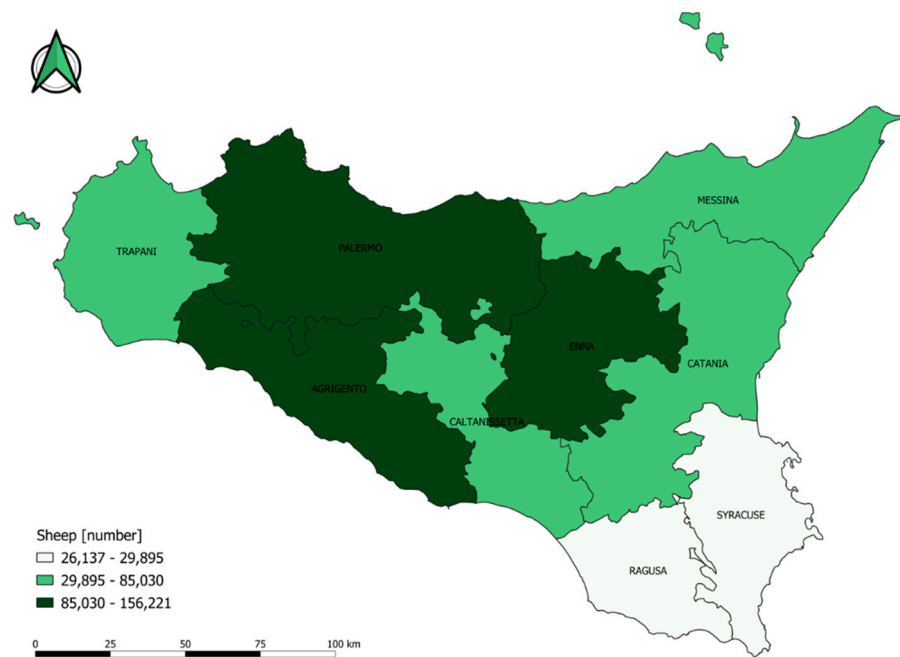

Figure 4. Sheep distribution within the study area (Sicily) at a provincial level.

As this research study focused on the evaluation of the yearly shared wool as potential natural fiber to be used as building material, by using Equation (2), a second thematic map was elaborated to show the distribution of the yearly sheared sheep wool within the study area (Sicily) at provincial level (Figure 5).
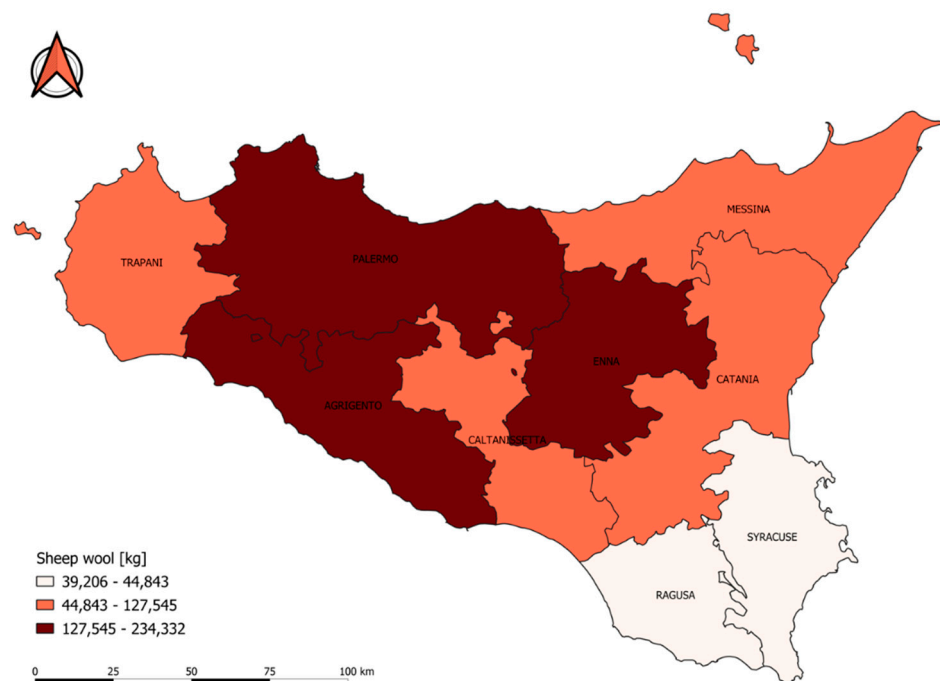
Figure 5. Distribution of the yearly sheared sheep wool within the study area (Sicily) at a provincial level.

Again, the provinces of Palermo (with an average of 170 t/year), Enna and Agrigento resulted as those ones with both the highest number of yearly sheared sheep, and the greatest availability of potential recyclable natural fibers.

In Figure 6 the territorial distribution of sheep farms is shown at municipal level. By observing these data, it is possible to notice that there is a difference with the two previously maps (Figures 4 and 5) related to the number of sheep and resulting shared wool, respectively. In fact, in this case, the municipalities of the provinces of Ragusa and Messina, and Syracuse, are characterized by the highest number of farms without correspondence with the number of sheep and shared wool.
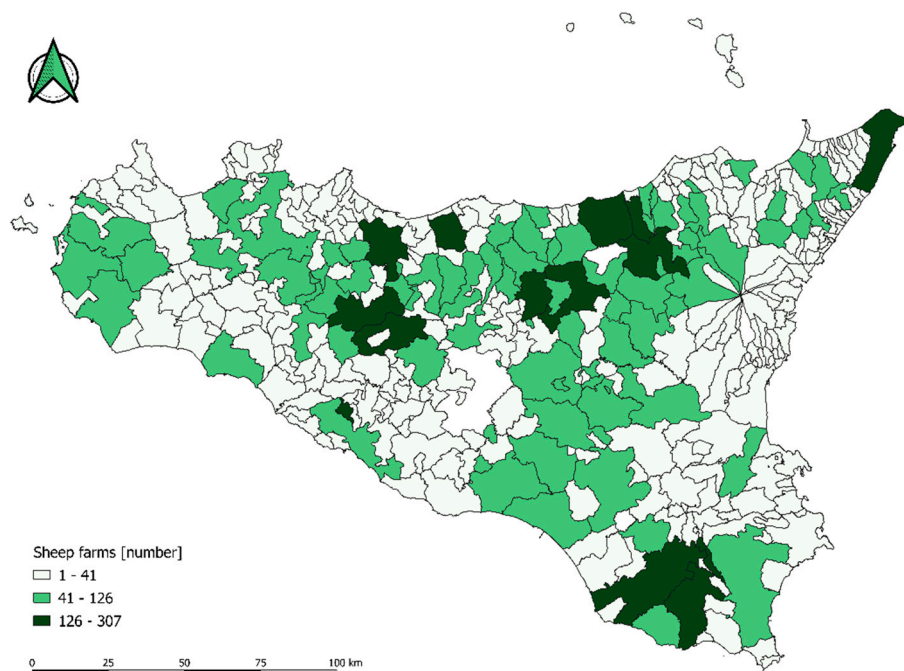
Figure 6. Sheep farm concentration at municipal level.

With the aim of producing a tailored heatmap based on the number of sheep farms, the polygon centroids were computed and applied for developing the heatmap (Figure 7). In detail, nine classes were considered with different concentration levels. Additionally, in this case, by analyzing this data elaboration, the highest concentration was observed in those territorial areas belonging to the provinces of Messina and Ragusa. Others high-concentration areas are localized on the provinces of Palermo, Agrigento, and Enna, by confirming the data elaborated by thematic maps (Figures 4 and 5).

A further tailored heatmap was elaborated by taking into account the number of sheep at province level.

For carrying out this analysis, nine classes were considered. By analyzing Figure 8 two mostly concentrated areas are clearly identified; the first one is localized among the provinces of Palermo and Agrigento, and the second one between Enna and Messina provinces.

As previously stated, the final aim of this study was the identification of the most suitable areas for detecting collection centers of shared wool, by minimizing all the impact deriving from the transport and logistic phases. As shown before, a discrepancy between data related to the number of sheep and the number of farms, was detected (i.e., great number of farms with few heads of sheep).
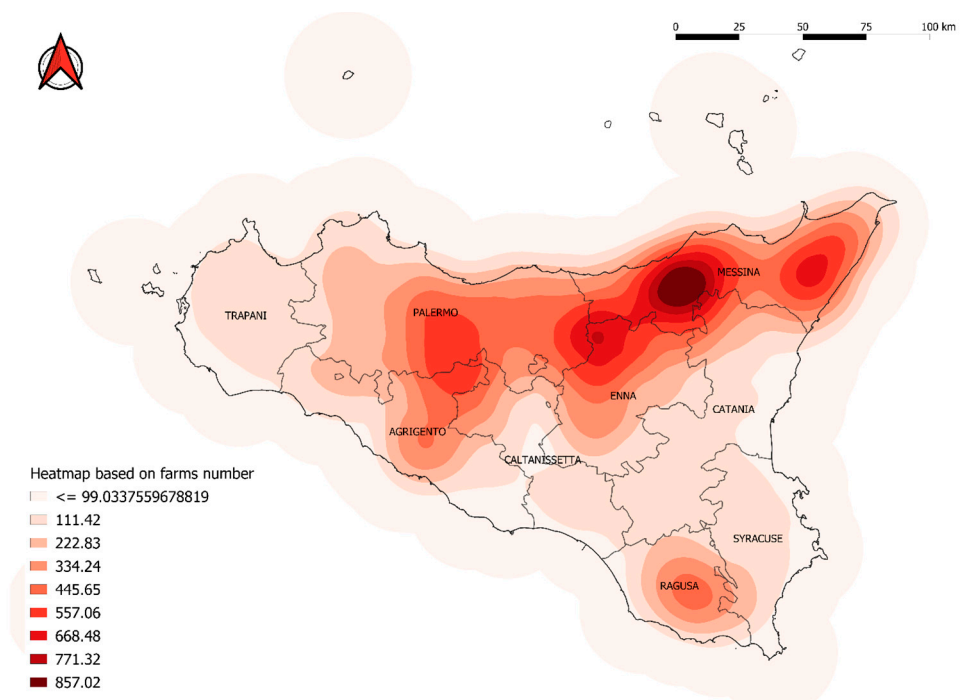
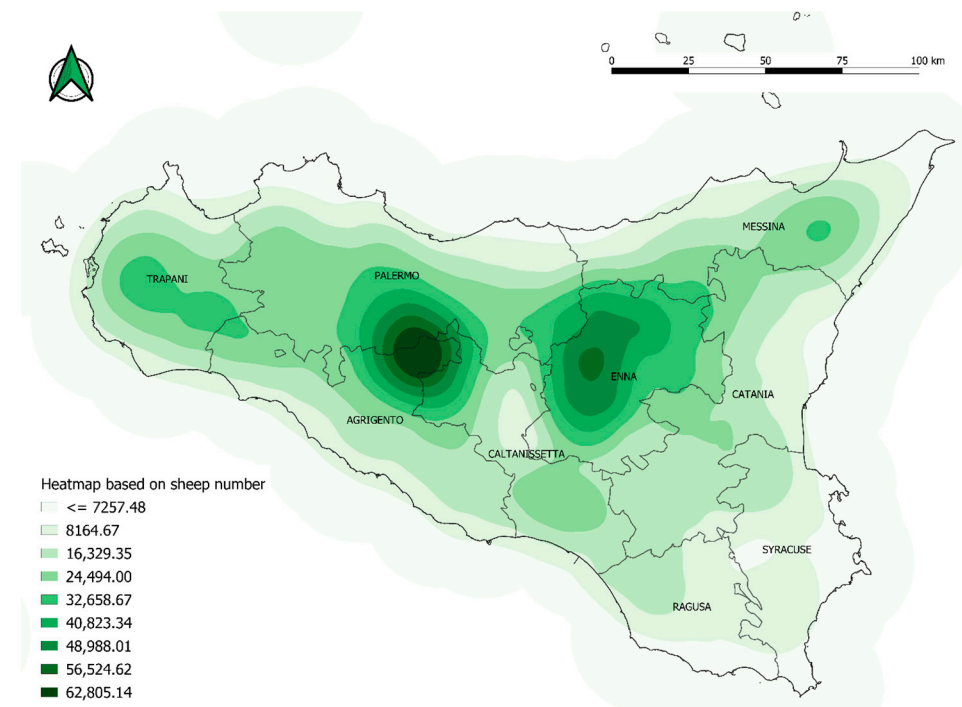**Figure 7.** Heatmap based on the distribution of sheep farms at provincial level.

Figure 8. Heatmap based on the distribution of sheep number at provincial level.

For this reason, data related to the number of farms and the yearly shared wool were computed together by a functional index, through the Equation (2). By overlapping data related farms and wool and considering tailored weights for, respectively, farms and sheep, a heatmap was elaborated (Figure 9).

Figure 9 shows the two highest concentration areas. The first one is localized between the provinces of Palermo, Caltanissetta, and Agrigento, and the second one was found between Enna and Messina provinces. A third suitable area, with less concentration, was detected between Trapani and Palermo provinces. In general, elaborations of data

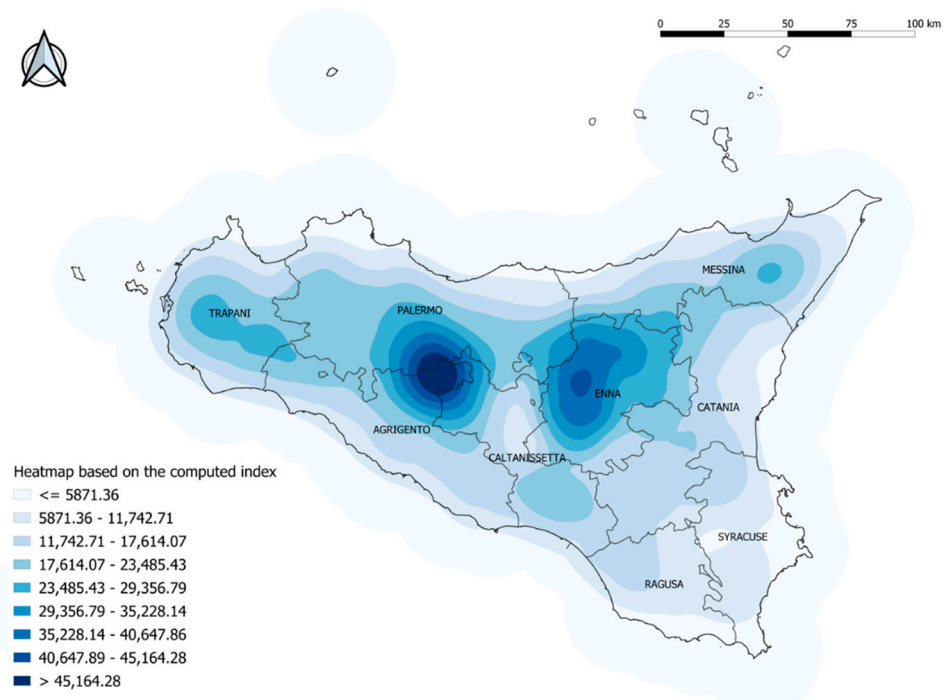demonstrated an almost uniform concentration on the north and central zone of the case study area.

Figure 9. Heatmap obtained through the computed index, at provincial level.

The obtained heatmap, reported in Figure 10, has been carried out by overlapping data on both the sheep farms and the sheep number, without considering the computed index reported in Equation (2).
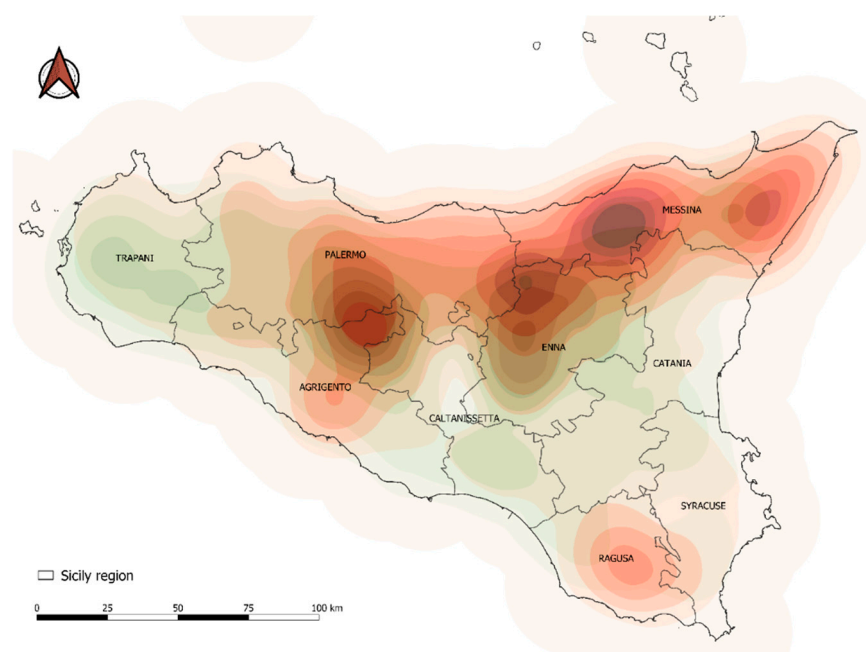

Figure 10. Heatmap obtained by overlapping data on sheep farms and sheep number, at provincial level.

By analyzing the results reported in Figure 10, the highest concentration areas were located in the central and north areas of Sicily, by confirming the results obtained by the weighted heatmap reported in Figure 9. Moreover, another area highly concentrated is highlighted on the Ragusa province.

Finally, by evaluating the results shown in the last two heatmaps (Figures 9 and 10), another elaboration, in order to find the most suitable areas for localizing the shared collection centers, was performed (Figure 11).
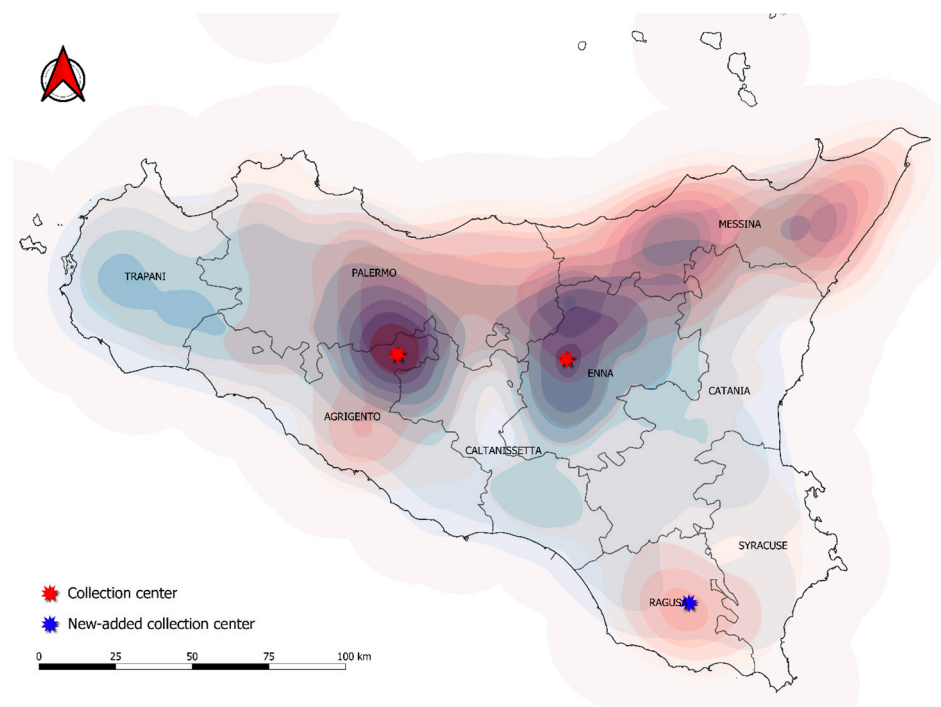

Figure 11. Identification and localization of new suitable collection centers.

By considering results from Figure 9, two collection centers could be clearly individuated, the first one localized in the province of Agrigento, close to the provincial boundaries of Caltanissetta and Palermo, and the second one within the province of Enna, close to Messina and Palermo provincial boundaries, reported in Figure 11 by a red symbol. Then, to also take into account data relating to the number of sheep farms reported in Figure 10, and with the aim of covering the south area of the Sicily, a third suitable area for detecting further collection center has been identified, as shown by a blue symbol. This possible third collection center was localized in the territorial area belonging to the province of Ragusa (Figure 11).

The obtained results could contribute at developing the sustainable whole chain for recovering and properly reusing SSW within the context of circular economy.

In detail, the development of the wool supply chain in a region such as Sicily is of particular importance because the huge volumes of woolen mass, if intercepted, may justify the costs for building and managing a hypothetical collection center, more than in other regions. Moreover, the valorization of this additional "product" resulting from sheep farming, is suitable to preserve cultural and rural heritage, in accordance with the Common Agricultural Policy (PAC) [31]. The PAC main objective is to pursue a reasonable standard of life form farmers and breeders of the European Union, to link farmers with society and above all with surroundings. The challenge is to avoid the abandonment of lands, and preserve the rural landscapes from all over Europe, trying to increase the rural economy by promoting employment in the agricultural sector, by managing resources coming from the community budget. Some weakness points, which limit the sheep wool waste possible reuse, and above all could be considered as the main cause of the low overall value of the

wool, were found in some common mistakes during the shearing and handling processes on farm. These could be easily addressed by awareness raising and training of the farmers, thus determining a better value of the waste product.

In order to convert this waste into a suitable new real resource, it is necessary to find new added value to balance its higher costs by improving co-operation among breeders (i.e., the pre-shearing wash phase), waste collectors, transporters, and recyclers, to ensure the maximum amount of SSW recovery and reuse. New uses of sheep wool are advised based on specific technological behaviors that offer added value for several applications within the green buildings sector. By following this new suitable whole chain for recovering and properly reusing SSW, in 2021 in Sicily region, a wool district (*Distretto Laniero Siciliano*) was found, with the aim to support the Sicilians' sheep breeders to improve techniques for wool trimming, handling, and selection, in order to increase wool added values and win the reluctance towards innovation and cooperative actions.

4. Conclusions

In Italy is estimated a yearly sheep wool production of around 9 thousand tons, by considering a sheep population of 6 million heads. Sheep wool is a good thermal acoustical insulation material and reinforcement fibers for bio composites, by supporting green building materials production. The aim of this study was to identify the most suitable areas for the localization of new shared wool collection centers in order to sustainably develop the whole chain for recovering and properly reusing the livestock waste of sheep wool. To achieve this aim, data supplied by National Zootechnical Registry of the Italian Ministry of Health (IZS) and GIS-based maps were evaluated and combined. In detail, the sheep livestock farming activity was deeply investigated by elaborating data-related sheep livestock farming surface areas, related wool production, and distribution of farms, for producing GIS thematic maps and heatmaps. The achieved results could represent a useful dataset of information to plan suitable locations of collection centers by reducing the distances from the territorial areas where these by-products are highly produced (i.e., from the sheep farms to the collection centers), with an advantage in terms of costs, but also in terms of social and environmental impacts, due to the logistics and supply of sheep wool waste.

By evaluating the obtained results two collection centers were clearly individuated, the first one localized in the province of Agrigento, and the second one within the province of Enna. Furthermore, a possible third collection center has been identified within the territorial area belonging to the province of Ragusa (south area of the Sicily), by taking into account also data relating to the farms number. These results could contribute at developing the sustainable whole chain for recovering and properly reusing SSW within the context of circular and green economy. Results obtained in this study represent basic information for defining a new wool chain and therefore new possible capitalization in a structured way. The huge amount of this livestock wastes could be reduced with positive effects on the environment and on humans and animals' welfare. Moreover, by encouraging sheep farmers to improve practice farming, including care of animals, a high quality of wool could be obtained, and this high quality wool could be suitable for new alternative uses as building materials. In the future, further investigations are required about aspects that were not addressed in this study, e.g., water supply for wool washing, water outlet after treatment, different kind of possible wool storage and packaging.

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References

1. Wilson, D.C.; Velis, C.A. Waste management—Still a global challenge in the 21st century: An evidence-based call for action. *Waste Manag. Res.* **2015**, *33*, 1049–1051. [CrossRef] [PubMed]
2. Kumar, A.; Agrawal, A. Recent trends in solid waste management status, challenges, and potential for the future Indian cities—A review. *Curr. Res. Environ. Sustain.* **2020**, *2*, 100011. [CrossRef]
3. European Commission. *The European Green Deal*; Cambridge University Press: Brussels, Belgium, 2019; Volume 53, p. 24. [CrossRef]
4. He, K.; Zhang, J.; Zeng, Y. Knowledge domain and emerging trends of agricultural waste management in the field of social science: A scientometric review. *Sci. Total Environ.* **2019**, *670*, 236–244. [CrossRef]
5. Bories, C.; Borredon, M.E.; Vedrenne, E.; Vilarem, G.; Agamuthu, P. Challenges and Opportunities in Agro-waste Management: An Asian Perspective What is AgroWaste? *J. Environ. Manag.* **2009**, *143*, 186–196. [CrossRef] [PubMed]
6. Selvaggi, R.; Valenti, F.; Pecorino, B.; Porto, S.M.C. Assessment of tomato peels suitable for producing biomethane within the context of circular economy: A gis-based model analysis. *Sustainability* **2021**, *13*, 5559. [CrossRef]
7. Obi, F.; Ugwuishiwu, B.; Nwakaire, J. Agricultural waste concept, generation, utilization and management. *Niger. J. Technol.* **2016**, *35*, 957–964. [CrossRef]
8. Liuzzi, S.; Sanarica, S.; Stefanizzi, P. Use of agro-wastes in building materials in the Mediterranean area: A review. *Energy Procedia* **2017**, *126*, 242–249. [CrossRef]
9. Toop, T.A.; Ward, S.; Oldfield, T.; Hull, M.; Kirby, M.E.; Theodorou, M.K. AgroCycle—Developing a circular economy in agriculture. *Energy Procedia* **2017**, *123*, 76–80. [CrossRef]
10. Vasilca, I.-S.; Nen, M.; Chivu, O.; Radu, V.; Simion, C.-P.; Marinescu, N. The Management of Environmental Resources in the Construction Sector: An Empirical Model. *Energies* **2021**, *14*, 2489. [CrossRef]
11. Li, Y.; Rong, Y.; Ahmad, U.M.; Wang, X.; Zuo, J.; Mao, G. A comprehensive review on green buildings research: Bibliometric analysis during 1998–2018. *Environ. Sci. Pollut. Res.* **2021**, *28*, 46196–46214. [CrossRef]
12. Zuo, J.; Zhao, Z.Y. Green building research-current status and future agenda: A review. *Renew. Sustain. Energy Rev.* **2014**, *30*, 271–281. [CrossRef]
13. Parlato, M.C.M.; Porto, S.M.C. Organized framework of main possible applications of sheep wool fibers in building components. *Sustainability* **2020**, *12*, 761. [CrossRef]
14. Mansour, E.; Marriott, R.; Ormondroyd, G. Sheep Wool Insulation for the Absorption of Volatile Organic Compounds. *Green Mater.* **2016**, *4*, 1–7. [CrossRef]
15. Allafi, F.; Hossain, S.; Lalung, J.; Shaah, M.; Salehabadi, A.; Ahmad, M.I.; Shadi, A. Advancements in Applications of Natural Wool Fiber: Review. *J. Nat. Fibers* **2020**, *19*, 497–512. [CrossRef]
16. Parlato, M.C.M.; Cuomo, M.; Porto, S.M.C. Natural fibers reinforcement for earthen building components: Mechanical performances of a low quality sheep wool ("Valle del Belice" sheep). *Constr. Build. Mater.* **2022**, *326*, 126855. [CrossRef]
17. Pulido, A.F.; Gaspar, P.; Mesías, F.J.; Escribano, A.J.; Escribano, M.; Pulido, F. Characterization of Production Systems and Marketing Strategies of Iberian Pig Farms in SW Spain. In *Book of Abstracts of the 64th Annual Meeting of the European Federation of Animal Science*; Wageningen Academic Publishers: Wageningen, The Netherlands, 2013; ISBN 9789086862283. Available online: https://www.wageningenacademic.com/pb-assets/wagen/files/e-books/open_access/9789086867820eaap2013-e.pdf (accessed on 30 March 2022).
18. Zoccola, M.; Montarsolo, A.; Mossotti, R.; Patrucco, A.; Tonin, C. Green Hydrolysis as an Emerging Technology to Turn Wool Waste into Organic Nitrogen Fertilizer. *Waste Biomass Valorization* **2015**, *6*, 891–897. [CrossRef]
19. Florea, I. The Actual Situation of Sheep's Wool Capitalization in Romania. *Bull. UASVM Anim. Sci. Biotechnol.* **2018**, *75*, 2. [CrossRef]
20. Zach, J.; Hroudova, J.; Brozovsky, J. Study of Hydrothermal Behavior of Thermal Insulating Materials Based On Natural Fibers. *Int. J. Civ. Environ. Struct. Constr. Archit. Eng.* **2014**, *8*, 995–998.
21. Rajabinejad, H.; Bucişcanu, I.I.; Maier, S.S. Current approaches for raw wool waste management and unconventional valorization: A review. *Environ. Eng. Manag. J.* **2019**, *18*, 1439–1456. [CrossRef]

22. Fantilli, A.P.; Sicardi, S.; Dotti, F. The use of wool as fiber-reinforcement in cement-based mortar. *Constr. Build. Mater.* **2017**, *139*, 562–569. [CrossRef]

23. Corbin, A.; Augarde, C. Fracture Energy of Stabilised Rammed Earth. *Procedia Mater. Sci.* **2014**, *3*, 1675–1680. [CrossRef]

24. Cheung, H.Y.; Ho, M.P.; Lau, K.T.; Cardona, F.; Hui, D. Natural fibre-reinforced composites for bioengineering and environmental engineering applications. *Compos. Part B Eng.* **2009**, *40*, 655–663. [CrossRef]

25. Mulenga, T.K.; Ude, A.U.; Vivekanandhan, C. Techniques for modelling and optimizing the mechanical properties of natural fiber composites: A review. *Fibers* **2021**, *9*, 6. [CrossRef]

26. Latif, E.; Lawrence, R.M.H.; Shea, A.D.; Walker, P. An experimental investigation into the comparative hygrothermal performance of wall panels incorporating wood fibre, mineral wool and hemp-lime. *Energy Build.* **2018**, *165*, 76–91. [CrossRef]

27. Ku, H.; Wang, H.; Pattarachaiyakoop, N.; Trada, M. A review on the tensile properties of natural fiber reinforced polymer composites. *Compos. Part B Eng.* **2011**, *42*, 856–873. [CrossRef]

28. Sajad, H.S.M.; Vahab, T. Strength and Fracture Behavior of Rammed-Earth Materials. *J. Mater. Civ. Eng.* **2019**, *31*, 4019228. [CrossRef]

29. Taha, E.; Abdel-Khalek, A.; Khalil, W.; Abdel Aal, N. Wool Production and Characteristics, Physiological and Haematological Parameters and Level of some Metabolic Hormones in Barki Ewes Shorn in Autumn as Alternative of Spring Shearing. *J. Anim. Poult. Prod.* **2018**, *9*, 415–422. [CrossRef]

30. Parlato, M.C.M.; Valenti, F.; Porto, S.M.C. Covering plastic films in greenhouses system: A GIS-based model to improve post use suistainable management. *J. Environ. Manag.* **2020**, *263*, 110389. [CrossRef]

31. European Commision Proposal for a regulation of the European Parliament and of the Council establishing rules on support for strategic plans to be drawn up by Member States under the Common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural. *Off. J. Eur. Union* **2018**, *0216*, 143.