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Sheep Wool Waste Availability for Potential Sustainable Re-Use and Valorization: A GIS-Based Model

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Abstract: Worldwide, 1.3 to 2.1 billion tons of agricultural waste are generated yearly, including livestock wastes (i.e., sheep wool), which create several critical environmental issues if not properly treated. In order to reduce the environmental issues related to the management and disposal, their use as natural fibers for green building components has notably developed over the last years. Indeed, sheep wool, which is a natural animal fiber that comes from shearing sheep fleece, is considered to be a problem of increasing concern due to its complex and difficult disposal management. Recently, several researchers have demonstrated that "low-quality wool" (i.e., not appropriate for textile uses) is suitable for the thermal and acoustic insulation of buildings. Indeed, thanks to its thermo-hygrometric and acoustic characteristics, it can be used as a reinforcing fiber for composite materials. In this study, a Geographic 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 through their Global Positioning System (GPS) coordinates, was developed and applied within the selected study area (i.e., the Sicily region). The aim was to identify the territorial areas highly characterized by this kind of waste and therefore most suitable for localizing new shared sheep wool collection centers to sustainably manage the reuse of this waste as a potential green building component.

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

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Citation: Midolo, G.; Porto, S.M.C.; Cascone, G.; Valenti, F. Sheep Wool Waste Availability for Potential Sustainable Re-Use and Valorization: A GIS-Based Model. *Agriculture* **2024**, *14*, 872. https://doi.org/10.3390/agriculture14060872

Academic Editors: Eugenio Cavallo, Carlo Bisaglia and Francesco Marinello

Received: 2 May 2024
Revised: 26 May 2024
Accepted: 29 May 2024
Published: 30 May 2024

1. Introduction

The increase in global waste generation is one of the world's most important environmental issues [1]. This phenomenon largely depends on the population growth, economic growth, and accelerated urbanization, which mainly involve developing countries. It has been estimated that by 2050, the annual generation of waste will reach 27 billion tons worldwide [2]. Therefore, finding suitable solutions and technologies aimed at minimizing waste generation by adopting proper waste disposal management or waste-to-value processes is urgently needed.

Adopting non-appropriate waste management leads to serious environmental problems such as air, soil, and water pollution as well as the accumulation of wastes in landfills, which not only requires dedicated space but can also be harmful to human health. Political strategies such as the European Green Deal have the overall goal of reducing gas emissions by 55% by 2030 and achieving climate neutrality by 2050 [3]. One of the goals is to reduce waste by promoting its recycling and more sustainable management. Similarly, the 2030 Agenda, with its 17 Strategy Development Goals (SDG), aims to promote sustainable development [2]. Indeed, SDG 12 promotes a model of sustainable consumption and production characterized by the recycling and reuse of waste through the adoption of modern and environmentally friendly practices [4]. Globally, about 1 of the 7–10 billion tons of waste generated annually [5] comes from the agricultural sector, accounting for approximately 10% [6]. To address these challenges, it is necessary to find tailored solutions not only to mitigate climate change but also to develop circular economies in developing countries [7,8]. Today, it is important to recognize that the agroecosystems produce much more than the agriculture sector, and so the waste generated by the agricultural sector is an equally important but often disregarded part of production [9]. However, in recent years, there has been greater awareness of the potential of agricultural waste and its potential to be usable as raw materials through the adoption of innovative recycling technologies in different production sectors [10,11]. Among the most investigated agricultural wastes in the literature are crop residues (i.e., leaves, bark, stalks, straw, weeds), livestock wastes (i.e., urine, manure, wash water, milk wastes, feed wastes, wool, feathers), and agro-industrial wastes (i.e., pulp, molasses, hulls) [9]. There are many examples of biorefineries that can be developed for the valorization of waste to produce energy, fossil fuels, chemical products, materials, fibers, food ingredients, films, etc. [10–12]. They exist in a liquid or solid form, and their composition depends on the specific agricultural activity carried out to produce them [13]. Among the vast amounts of agricultural waste produced annually, sheep wool waste is included. Sheep wool is a natural fiber obtained through the shearing of sheep fleece. Approximately 60% of sheep wool is composed of keratin protein fibers, while the remaining 40% is divided into moisture, fat, sheep sweat, and impurities [14]. Wool from Italian sheep farms is considered unsuitable for the textile sector due to its large diameter and is classified as a "low-quality fiber". In accordance with Regulation (EC) No 1069/2009 [15] and Regulation (EU) No 142/2011 [16], wool is classified as special waste and must be sterilized at 130 °C before its disposal to reduce its high bacterial load. In addition, these European regulations require farmers to quickly dispose of wool. Achieving the rapid disposal of wool is sometimes a difficult issue, leading to illegal practices such as storage, transport, and disposal, e.g., burning or burying, which have a severe environmental impact. The significant production of this waste represents a serious problem for environmental pollution and landscape quality, especially in rural areas, with potential for toxicity to air, water, plants, animals, and humans due to the high bacterial load [13]. For this reason, sheep wool waste is nowadays considered a solid waste of growing concern due to the complex management of its disposal. Nevertheless, because raw wool from shorn sheep is generally unsuitable for textile use, this waste has recently garnered the attention of researchers and scientists, who see significant potential for its use in various sectors, including construction [17–20]. By repurposing sheep wool as a new raw material, it is possible to produce innovative building materials and components that comply with eco-friendly construction criteria and environmental certifications (e.g., BREEAM, LEED, DGNB, and Green Mark). Wool fibers' properties, such as high elasticity, good tensile strength, fireproof capacity, and high hygroscopic power, make them excellent for the building sector, especially for thermal and acoustic insulation [18]. Examples include 100% sheep wool soft mats and rigid or semi-rigid panels made from sheep wool (70–80%) and polyester fibers (20–30%), as well as additives for composite materials. These properties can be adopted in different sectors in place of non-renewable and toxic resources like mineral wool, plastics, and foams that not only pollute but also pose harmful effects on human health [12]. Effectively utilizing agricultural waste involves five distinct stages: collection, storage, treatment, transfer, and usage. Each of these phases necessitates the integration of innovative technologies, fresh perspectives, incentivizing mechanisms, dedicated policies, and, above all, a novel approach to waste management in agriculture. Thus, the overarching objective of this study is to achieve both the production of recyclable waste products and the minimization of non-recyclable waste reintroduction into the environment [7]. Following the steps to develop an effective valorization process, the critical initial phase is collection and storage before any treatment or valorization procedures can commence. To this end, it is imperative to accurately quantify and pinpoint the territorial areas where waste is generated. The successful management of the collection and storage phases of wool waste hinges on an initial assessment of its availability and location.

Therefore, the aim of this study was to develop a Geographic Information System (GIS)-based model by using the open-source software QGIS (ver. 3.10.11) to quantify and localize available sheep wool waste for valorization with the objective of enhancing the sustainability of the entire supply chain through the establishment of suitable pre-treatment collection centers. In this context, GIS-based approaches are widely utilized worldwide across various sectors and are embraced as decision-making tools [21–24]. The application of GIS tools can effectively address location–allocation issues for biomass, waste, and by-products while minimizing the economic and environmental impacts associated with establishing new value chains, such as the wool chain in Sicily [25]. Numerous studies have demonstrated that GIS is the most suitable decision support tool for identifying sustainable strategies for managing new value chains [26,27]. The goal is to pinpoint the areas most characterized by this type of waste, making them ideal for new wool waste collection centers. To sustainably manage the reuse of this waste, it is crucial to minimize the environmental impact related to the logistics and storage phases [28,29]. Poorly chosen locations for future collection centers, distant from areas of high wool waste production, would significantly increase the environmental impacts due to higher CO2 emissions from transportation. Using GIS to identify regions where wool is predominantly produced is a crucial first step in developing a new supply chain for "low-quality wool". This approach can significantly reduce, reuse, and recycle wool waste, preventing illegal disposal and fostering the creation of new products in line with circular economy principles [30,31].

2. Materials and Methods

2.1. Study Area

The Sicily region was selected as the study area for the development of the GIS-based model. According to the data provided by the latest census on 31 December 2022 by the Italian National Institute of Statistics (ISTAT), more than 6 million sheep are raised in Italy (Table 1). Sheep farming is an important source of income for Italian farming families as it not only produces goods such as milk and meat but also contributes to rural employment, the local economy, and landscape conservation. Sheep farming is widespread in all regions of Italy, but some regions are particularly well known for this livestock activity. In Italy, Sardinia and Sicily are the two regions with the highest number of sheep, with 3,074,452 for Sardinia and 738,800 for Sicily, respectively (Table 1).

Table 1. Consistency of Italian sheep population divided by region (ISTAT).

Italian Regions	Number of Sheep
Sardinia	3074.452
Sicily	738.800
Lazio	642.034
Tuscany	358.369
Calabria	200.474
Abruzzo	188.595
Campania	186.338
Basilicata	178.918
Apulia	178.438
Lombardy	137.123
Marche	137.033
Umbria	128.268
Piedmont	122.891
Trentino-Alto Adige	74.954
Veneto	70.090
Molise	66.711
Emilia-Romagna	49.267
Friuli Venezia Giulia	20.802
Liguria	11.520
Aosta Valley	2.469
Total	6567.546

The Sicily region was chosen as the focal area for developing the GIS-based model. As of the latest census on 31 December 2022, conducted by the Italian National Institute of Statistics (ISTAT), in Italy, there are 6.57 million sheep (Table 1).

Sheep farming plays a crucial role in generating income for Italian farming families, providing not only essential products like milk and meat but also making significant contributions to local employment, the regional economy, and landscape preservation. While sheep farming is prevalent throughout Italy, certain regions are particularly known for their robust livestock activity. As previously mentioned, Sardinia and Sicily stand out as the two regions with the highest sheep populations. In Sardinia, a well-established supply chain has already been developed to enhance the value of sheep wool waste. Specifically, the dense fiber composition of Sardinian sheep wool lends itself to resistance, making it ideal for the production of loom carpets, and it is currently utilized in collections crafted by renowned designers. However, in Sicily, despite the significant quantity of sheep wool, the issue of disposal persists without any strategies for its valorization or recovery. This challenge, coupled with Sicily being the second-largest region nationally in terms of sheep numbers, led to its selection as the focus area for this study.

Sicily, encompassing 26,000 km^2, is considered the largest island in the Mediterranean region. It is one of the twenty regions of Italy, and it has nine different provinces: Palermo, Catania, Messina, Ragusa, Caltanissetta, Agrigento, Trapani, Enna, and Syracuse (Figure 1).

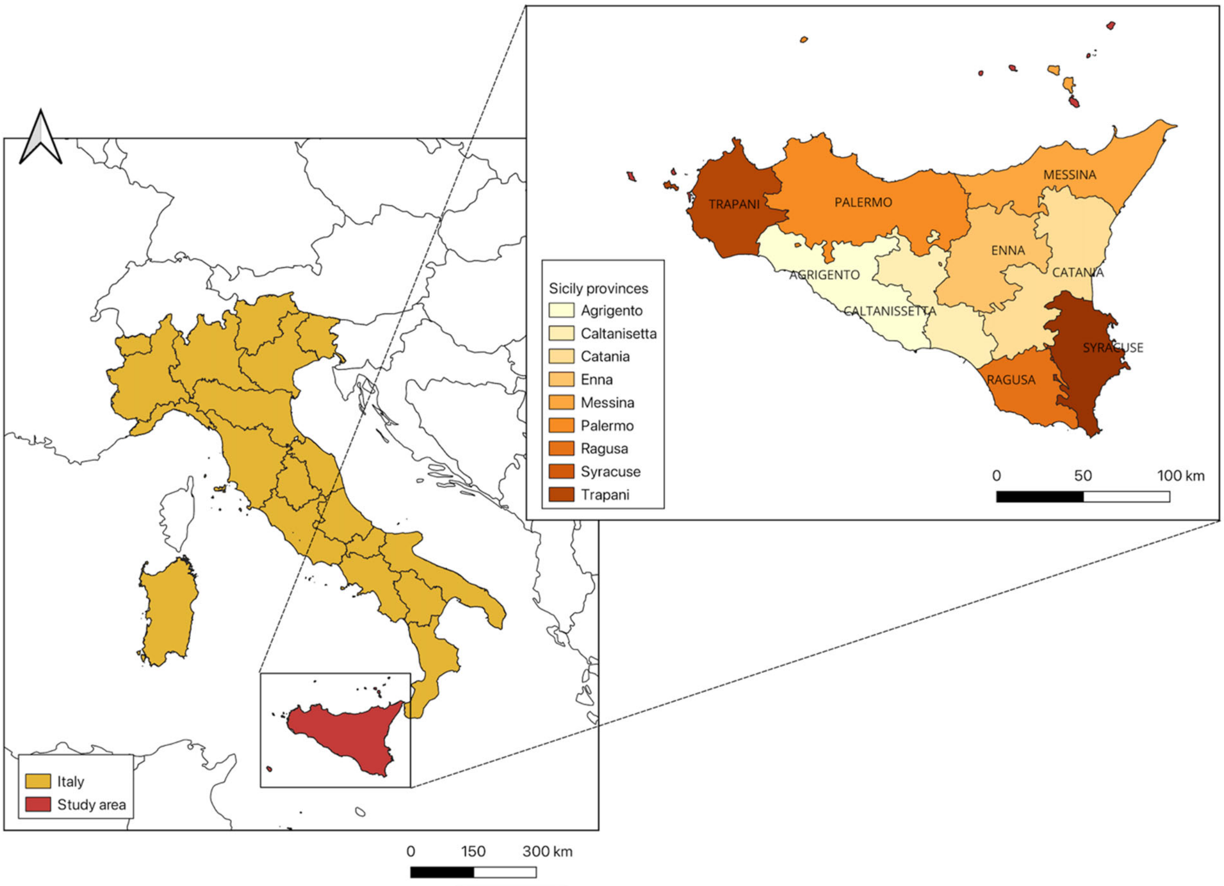


Figure 1. Selected study area. Elaboration obtained by using QGIS software (ver. 3.10.11).

Sicily's landscape comprises over 62% mountains, 24% hills, and the remaining 14% as plains. The climate is characterized by mild, wet winters and hot, dry summers. This diverse terrain and climate make Sicily particularly favorable to breeding a robust sheep breed known for its adaptability to various climates and terrains—the "rustic breed". The National Zootechnical Registry of the Italian Ministry of Health (IZS) highlights mixed breeds as the most commonly raised breeds in Sicily, resulting from crossbreeding for enhanced productivity and resilience to climatic and sanitary conditions. Other prevalent breeds include the "Valle del Belice" sheep, the "Sarda", "Pinzirita", and "Comisana" breeds. Despite variations in conformation, adaptability, and production, the wool produced by these breeds in Sicily is generally considered of a "low quality" [13]. As these sheep are primarily bred for milk and meat, little attention is given to the wool. Unlike breeds specifically raised for wool production, such as the merino breed, Sicilian and Italian wool breeds tend to have coarse fibers that are unsuitable for textiles.

Recent studies, however, suggest that despite its textile limitations, Sicilian wool possesses unique chemical and physical characteristics suitable for use in various sectors, including the construction sector [17–20]. Transforming this agricultural waste into a raw material not only prevents environmental pollution resulting from illegal disposal but also contributes to a significant reduction in CO_2 emissions. Utilizing this natural, readily available, and recyclable resource underscores its potential for sustainable practices. The urgency to address the wool disposal issue in Sicily is evident, surpassing the concerns in other Italian regions. Despite a national decrease of 8.5% in recent years (especially in 2020–2021), Sicily bucks the trend, experiencing an increase in sheep numbers, as illustrated in Figure 2, emphasizing the critical need for a viable solution to wool disposal in the region.

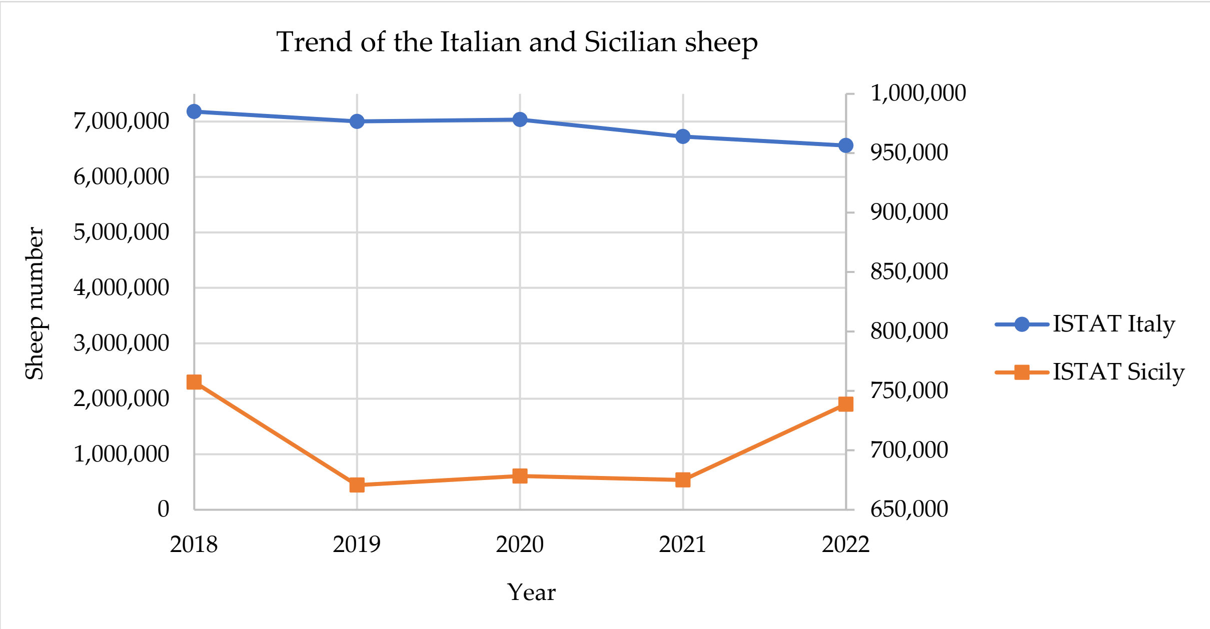


Figure 2. Consistency of Italian sheep population during the 2018–2022 time interval (ISTAT).

2.2. Data Analysis

The data used in this study were sourced from two distinct information outlets. Initially, information was gathered from the national livestock registry database (BDN), which offers insights into the consistency of Italian livestock. This allowed for the analysis of data related to the number of sheep and herds present in the chosen study area as of 31 December 2022. The acquired information was related to each of the nine Sicilian provinces, providing details for each farm, including the number of sheep and a unique farm code identifying the location where the animals are raised. Subsequently, the veterinary information systems portal (VetInfo) was accessed to obtain the geographic coordinates of each herd within the selected study area. This was achieved by utilizing the farm codes previously extracted from the national livestock registry database (BDN). After the data extraction and preparation phase, a comprehensive database was established with the objective of quantifying and locating both sheep and farms within the study area.

The collected data were then processed using a Geographic Information System (GIS)-based model. By identifying the geographic areas with a higher production of livestock waste, specific territorial areas were identified for the potential location of future collection centers. This strategic approach aimed to minimize the environmental impacts associated with the logistics and supply phase of greasy wool, thereby enhancing the sustainability of the entire process. All spatial analyses were conducted using the open-source software QGIS (ver. 3.10.11), utilizing the regional technical map (RTM 2008) as the base map for carrying out both the thematic maps and heatmaps. Through the analysis of the acquired data, the software enabled the identification of all farms along with their GPS coordinates. This facilitated the identification of not only the provinces with the highest number of farms and sheep but also the specific territorial areas within each province.

In detail, several steps were followed, as reported in Figure 3, which presents a comprehensive depiction of the methodology's flowchart, providing a detailed account of the steps, inputs, intermediate outputs, and achieved results. After data preparation, GIS-based analyses were executed to generate both thematic maps and heatmaps. The steps involved included the localization of farms through their GPS coordinates for each individual province, the quantification of available sheep wool waste based on the number of animals per herd for each Sicilian province (utilizing the index reported by Parlato et al. [13]), and the territorial distribution of farms based on the number of sheep per individual province. In addition to these, further GIS-based analyses were carried out to develop heatmaps, including one based on the distribution of the number of Sicilian farms and another weighted by the number of sheep per farm (e.g., consistency).

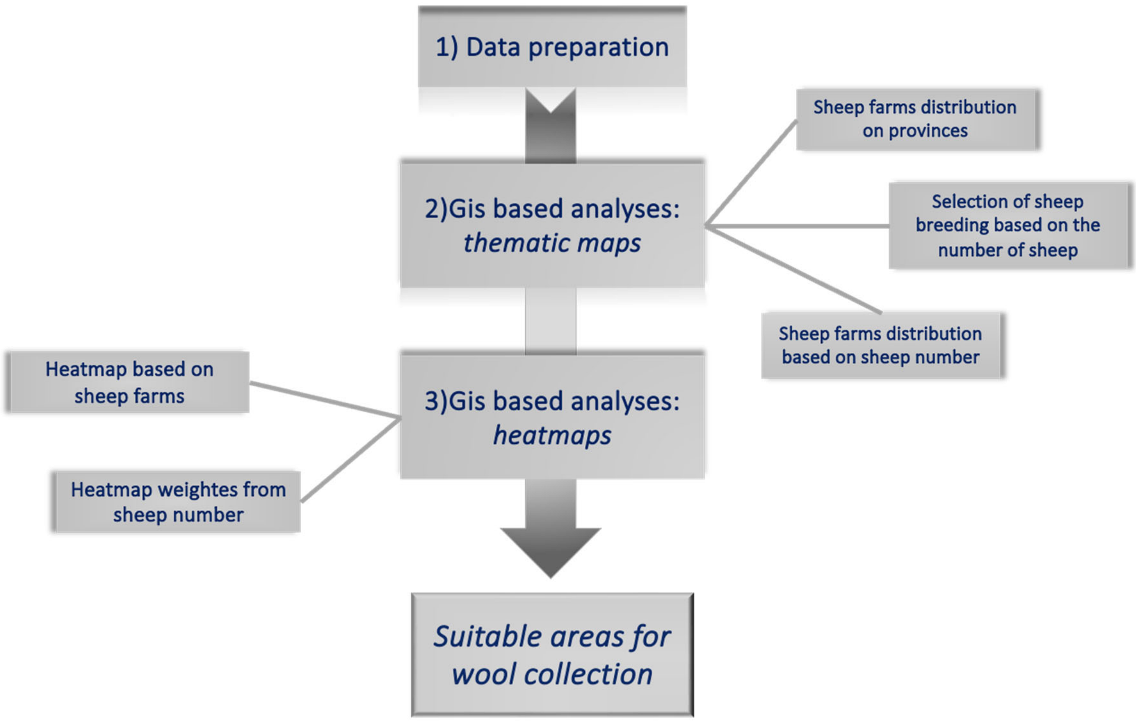


Figure 3. Flow Chart of Methodology Research.

3. Results and Discussion

The data concerning the number of farms and the population of sheep in Sicily were acquired through the analysis and processing of information obtained from the Vetinfo portal. To depict the distribution of sheep and the prevalence of livestock farms at the regional level, the collected data underwent organization, processing, and utilization in the development of the GIS-based model. This involved the creation of thematic maps followed by the production of heatmaps.

3.1. Thematic Maps

Firstly, the distribution of sheep farms across individual Sicilian provinces was investigated. The data obtained revealed a total of 7248 registered sheep farms in Sicily as of 31 December 2022. All 7248 farms were geographically localized using their GPS coordinates in GIS. The first thematic map was created by categorizing farms according to their respective provinces. As shown in Figure 4, each farm was represented by differently colored dots corresponding to its province, clearly delineating provincial boundaries. The results highlighted three notable Sicilian provinces with the highest concentration of farms. Specifically, Palermo, followed by Messina and Enna, reported 1775, 1581, and 1057 farms, respectively. These provinces together represent 61% of the total sheep farms in Sicily. The thematic map indicated that the central-northern region of the island hosts the majority of livestock farms for sheep breeding. Historically, this area has been a key point for livestock activities compared to provinces like Syracuse, which registers a lower farm count. This variation may be attributed to the extensive cultivation of protected crops in Syracuse, limiting the available open spaces for breeding activities [32].

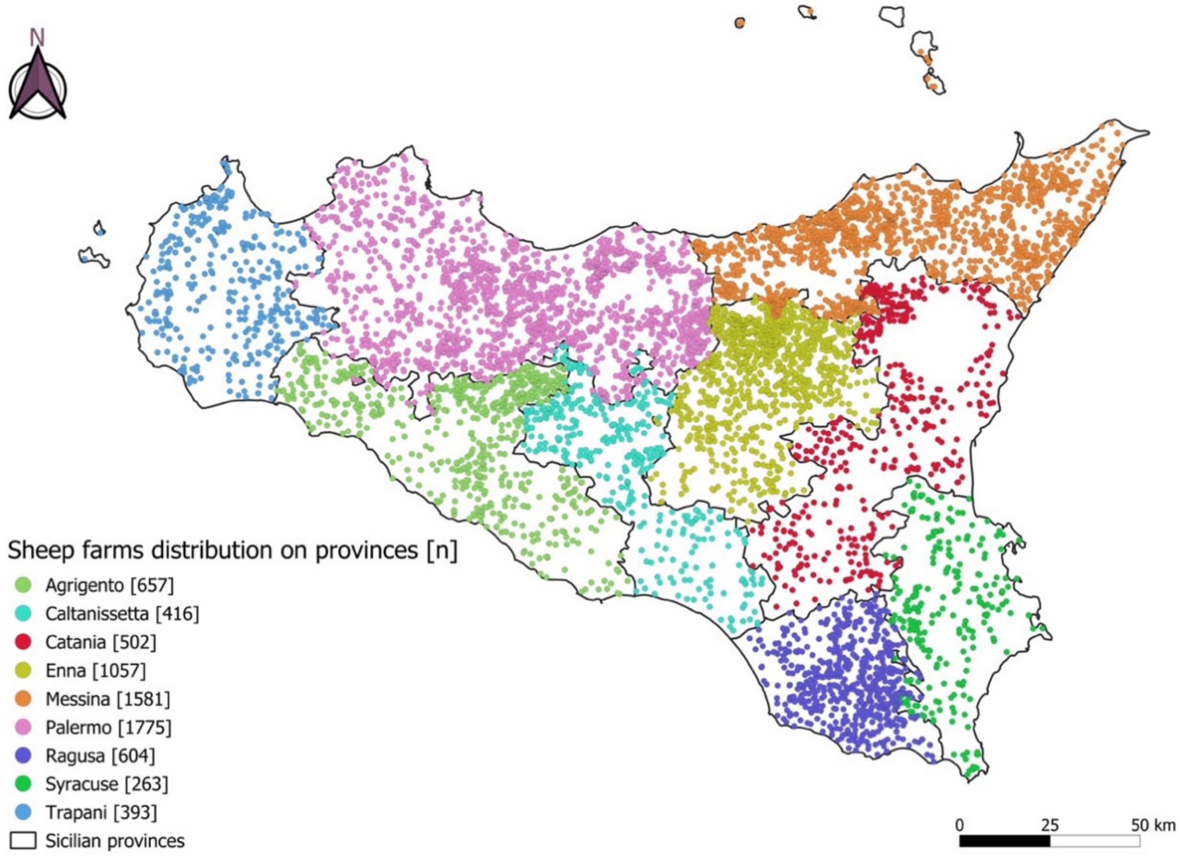


Figure 4. Sheep farms distribution in Sicilian provinces.

Subsequently, another thematic map was elaborated to assess the number of sheep for each identified farm. A specific selection criterion was applied, focusing only on livestock farms with a sheep count greater than zero based on the acquired data. Given the study's emphasis on valorizing wool waste, farms with zero sheep were excluded, as they are not involved in the process of delivering wool waste to collection centers. Therefore, only farms with a number of sheep greater than zero, indicative of wool waste production, were considered. This approach revealed that, of the total 7248 farms identified in the previous analysis, only 89% had a sheep count greater than zero. Consequently, compared to the initial thematic map, the number of farms in the study area decreased from 7248 to 6463 (an 11% reduction). As shown in Figure 5, only the farms denoted with a red symbol were considered. Despite the reduction in the number of farms, the thematic map still indicates that the highest concentration of sheep, represented by red dots, was situated in the province of Palermo, followed by the provinces of Messina and Enna. Particularly, the provinces of Messina and Ragusa had a larger number of excluded farms.

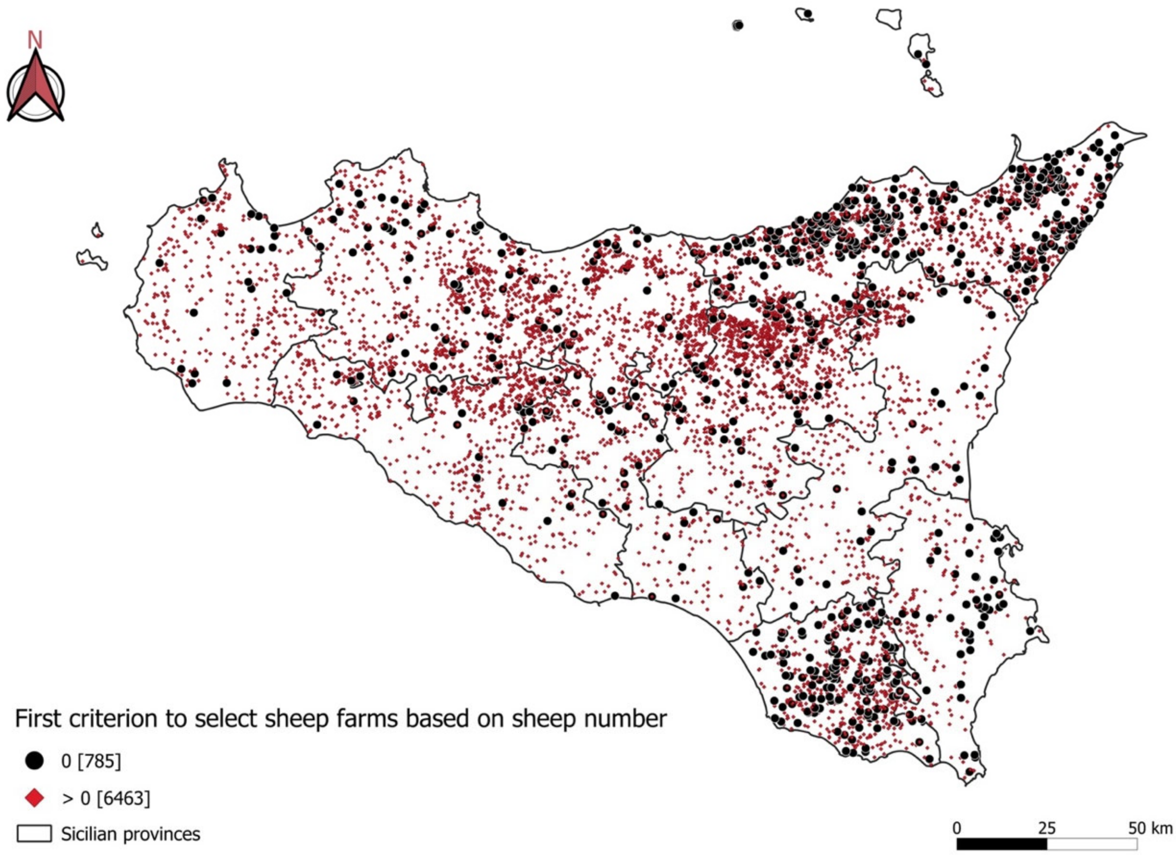


Figure 5. Distribution of the selected sheep farms.

Using the Jenks tool within the QGIS software, another thematic map was produced to depict the distribution of the 6463 localized sheep farms based on the number of their sheep. The farms were categorized into four classes determined by the Natural Breaks (Jenks) algorithm, aiming to identify natural groupings in the data for creating meaningful classes. This algorithm ensures maximum variance between classes and minimal variance within each class. The results are reported in Figure 6, highlighting that the majority of the Sicilian sheep farms had a modest number of animals, ranging from 1 to 103 sheep. This implies that 67% of the farms in Sicily were small-scale, while only 1% of the farms exhibited a substantial number of animals, ranging from 500 to 1700 sheep. Moreover, Figure 6 illustrates that farms with the lowest sheep count were predominantly situated in the northern and southern regions of Sicily, whereas those with the highest sheep count were concentrated in the central areas. The number of sheep per farm is a critical factor in identifying suitable territorial areas for establishing collection centers, as areas with a higher concentration of small farms typically involve increased transportation and supply costs for wool waste. It is noteworthy that provinces with the highest concentration of sheep farms may not necessarily coincide with those having the highest volume of wool waste; this value depends on the number of sheep per farm and is essential for the effective planning of future collection centers.

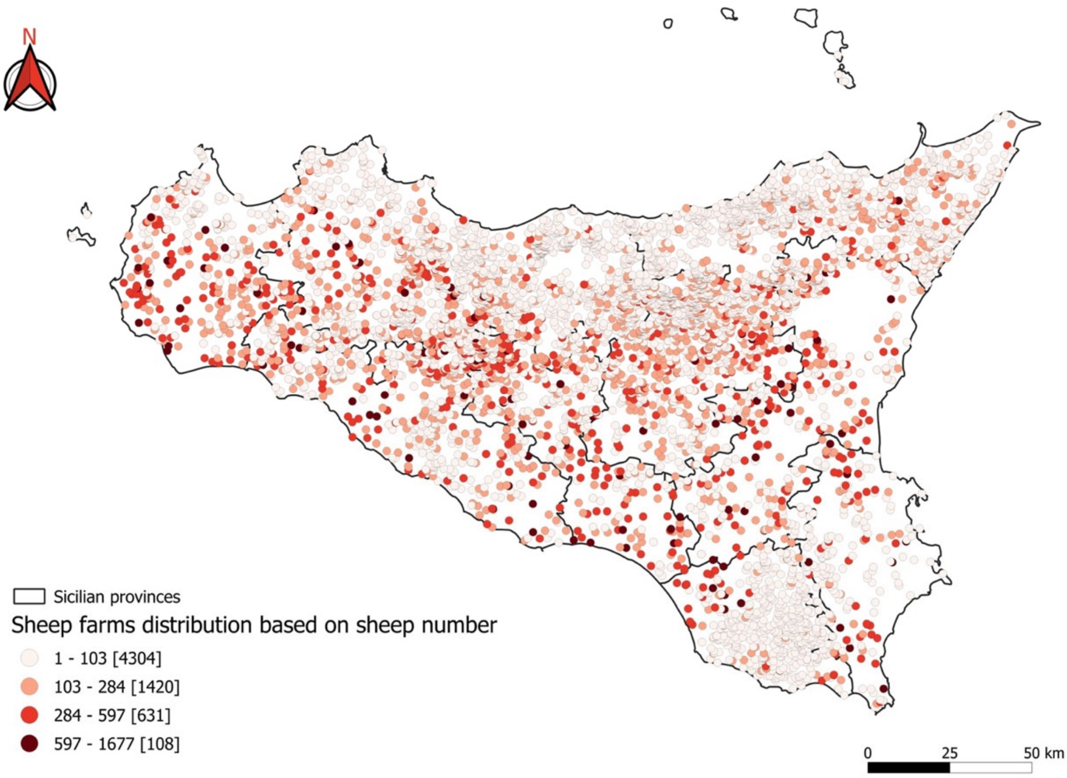


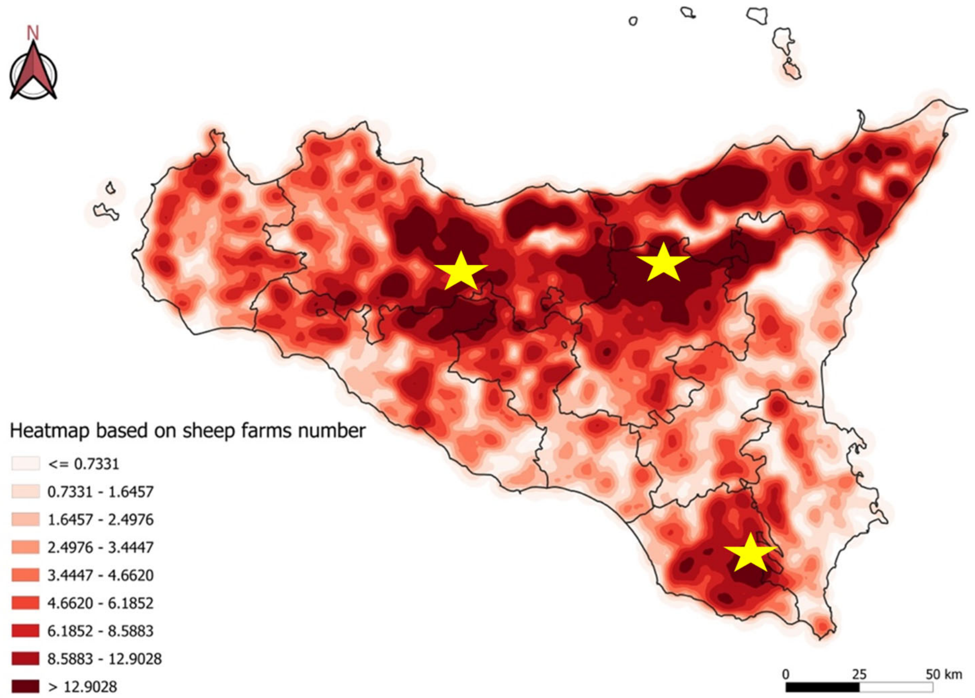
Figure 6. Distribution of the sheep farms according to their sheep number.

3.2. Heatmaps

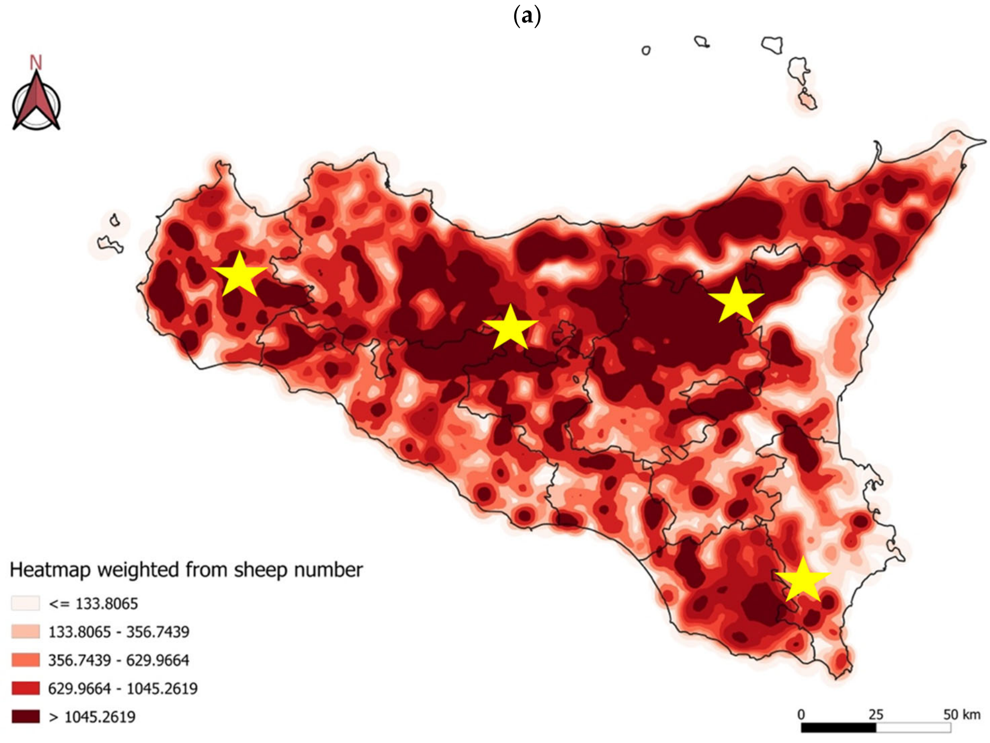
Adopting the Kernel Density Estimation (KDE) tool within the QGIS software, heatmaps were carried out based on the distribution of sheep farms to explore the territorial areas with the highest concentration of such farms. The KDE tool, widely used for assessing point events, was chosen for its simplicity in implementation and interpretation, specifically designed to effectively identify local spatial features. It generates a density grid from a given point vector layer, calculating the density by considering the quantity of points at each location, with greater concentrations yielding higher values. This process allows for the straightforward identification of "hotspots" and the clustering pattern exhibited by the points.

Analyzing this data processing, the highest concentration of sheep farms was observed in territorial areas belonging to the provinces of Palermo, Messina, Enna, and Ragusa. Specifically, the northern areas of Sicily, comprising various provinces in close proximity, showed the highest number of farms. In contrast, in the southern part of Sicily, only the province of Ragusa exhibited a higher concentration of farms. Based on this analysis, three suitable territorial areas for locating collection centers were identified, as depicted in Figure 7a.

As stated earlier, the provinces with the highest concentration of sheep farms may not necessarily coincide with those having the highest volume of wool. To address this, a new analysis was conducted, considering the number of sheep per each identified farm. An additional heatmap, reflecting the distribution of sheep farms, was generated by incorporating the number of sheep on each farm as a weight. The triangle kernel function was employed, and the quantile classification method, which divides classes to achieve roughly equal numbers of features in each class, was utilized to create five classes. This classification method was chosen for its effectiveness in illustrating rankings. The obtained results confirmed the findings presented in Figure 7a, identifying Messina, Palermo, and Enna as potentially suitable areas for establishing collection centers. However, when considering the number of sheep, the distribution was more evenly spread across the study area. In this case, four potentially suitable areas were identified, partially overlapping with those highlighted in Figure 7a. In addition to the three previously identified areas, the territorial area belonging to the province of Trapani was added, as reported in Figure 7b. Specifically, the areas depicted in Figure 7b are situated between the provinces of Palermo and Agrigento, between the provinces of Enna and Messina, and within the territorial areas of the provinces of Trapani and Ragusa, respectively.



(**a**)



(**b**)

Figure 7. (**a**) Heatmap of the sheep farms distribution; (**b**) weighted heatmap of the sheep farms distribution based on their consistency.

Analyzing the results from both heatmaps (Figure 7a,b), it is evident that the number of sheep per farm, and consequently the quantity of available wool waste, is key information for identifying suitable areas to establish collection centers. These data are fundamental for thorough and sustainable planning. For effective waste valorization, it is crucial to know where the waste is produced and its quantity to plan a sustainable logistics and supply phase. Given the partial overlap in the results, the four territorial areas marked with stars in Figure 7b were identified as potentially suitable for new collection centers. These areas are not only seen as potential collection sites but also as the starting points for the entire wool waste valorization chain. By establishing tailored collection and storage systems in these areas, it is possible to develop a sustainable wool waste valorization chain that minimizes environmental impacts, such as CO_2 emissions, from the supply phase.

4. Conclusions

In recent years, wool has attracted attention from researchers and scientists due to its properties, which include high elasticity, good tensile strength, fire resistance, and high moisture absorption capacity. Despite findings demonstrating wool as an excellent fiber for thermal and acoustic insulation [18], the substantial amount of produced wool waste remains a significant environmental concern, particularly in rural areas. This waste poses potential toxicity risks to air, water, plants, animals, and humans due to the high bacterial load. In response to this environmental challenge, there is growing interest in reusing wool waste as a potential resource.

The objective of this work was to develop a GIS-based model to quantify and locate available wool waste for valorization, aiming to enhance the sustainability of the entire supply chain by strategically placing pre-treatment collection centers. To achieve this, data from the National Livestock Register Database (BDN) and the Veterinary Information Systems Portal (VetInfo) were integrated and processed using the QGIS software. The results obtained could offer valuable insights for strategically planning the locations of collection centers, minimizing distances from areas abundant in wool waste, such as sheep farms. This approach not only improves cost efficiency but also addresses the social and environmental impacts associated with the logistics and supply of sheep wool waste.

Based on the obtained results, four territorial areas—between the provinces of Palermo and Agrigento, between the provinces of Enna and Messina, and within the provinces of Trapani and Ragusa—were identified as suitable for establishing collection centers. These results represent an initial step in developing a new wool supply chain in Sicily. Properly locating, storing, and processing wool waste can positively impact the environment by reducing illegal practices such as burning or burying. Additionally, establishing a wool supply chain presents a significant economic opportunity for the Sicily region, aligning with the principles of the circular and green economy by transforming waste into a valuable raw material.

Author Contributions: Conceptualization, F.V. and G.M.; methodology, F.V. and G.M.; software, F.V.; validation, F.V.; formal analysis, G.M.; investigation, G.M.; data curation, F.V.; writing—original draft preparation, G.M.; writing—review and editing, F.V.; visualization, F.V., S.M.C.P. and G.C.; supervision, F.V. All authors have read and agreed to the published version of the manuscript.

Funding: The research study was funded by the University of Catania through the 'Piano incentive per la ricerca di Ateneo 2020–2022-Linea 20 project on 'Engineering solutions for sustainable development of agricultural buildings and land (LANDSUS)' (ID: 5A722192152) coordinated by Professor Claudia Arcidiacono (University of Catania).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. FAO; IFAD; UNICEF; WFP; WHO. *The State of Food Security and Nutrition in the World 2022. Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable*; FAO: Rome, Italy, 2022. [CrossRef]
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*; European Commission: Brussels, Belgium, 2019; Volume 53, p. 24.
4. United Nations Resolution 70/1. Transforming Our World, The 2030 Agenda for Sustainable Development, Adopted by the General Assembly on 25 September 2015. Available online: https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/291/89/PDF/N1529189.pdf?OpenElement (accessed on 1 May 2024).
5. 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]
6. 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]
7. Obi, F.; Ugwuishiwu, B.; Nwakaire, J. Agricultural waste concept, generation, utilization and management. *Niger. J. Technol.* **2016**, *35*, 957–964. Available online: https://www.ajol.info/index.php/njt/article/view/145135 (accessed on 1 May 2024). [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. Alan, H.; Köker, A.R. Analyzing and mapping agricultural waste recycling research: An integrative review for conceptual framework and future directions. *Resour. Policy* **2023**, *85*, 103987. [CrossRef]
10. Valenti, F.; Parlato, M.C.M.; Pecorino, B.; Selvaggi, R. Enhancement of sustainable bioenergy production by valorising tomato residues: A GIS-based model. *Sci. Total Environ.* **2023**, *869*, 161766. [CrossRef]
11. Valenti, F.; Selvaggi, R.; Pecorino, B.; Porto, S.M. Bioeconomy for sustainable development of biomethane sector: Potential and challenges for agro-industrial by-products. *Renew. Energy* **2023**, *215*, 119014. [CrossRef]
12. Zhao, J.R.; Zheng, R.; Tang, J.; Sun, H.J.; Wang, J. A mini-review on building insulation materials from perspective of plastic pollution: Current issues and natural fibres as a possible solution. *J. Hazard. Mater.* **2022**, *438*, 129449. [CrossRef]
13. Parlato, M.C.M.; Valenti, F.; Midolo, G.; Porto, S.M.C. Livestock wastes sustainable use and management: Assessment of raw sheep wool reuse and valorization. *Energies* **2022**, *15*, 3008. [CrossRef]
14. 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]
15. Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009, Laying Down Health Rules as Regards Animal by-Products and Derived Products not Intended for Human Consumption and Repealing Regulation (EC) No 1774/2002 (Animal by-Products Regulation). 21 October 2009. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R1069 (accessed on 1 May 2024).
16. Regulation (EU) No 142/2011 of 25 February 2011, Implementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council Laying Down Health Rules as Regards Animal by-Products and Derived Products Not Intended for Human Consumption and Implementing Council Directive 97/78/EC as Regards Certain Samples and Items Exempt from Veterinary Checks at the Border under that Directive (Text with EEA Relevance). 25 February 2011. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011R0142 (accessed on 1 May 2024).
17. 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]
18. Tiza, T.M.; Singh, S.K.; Kumar, L.; Shettar, M.P.; Singh, S.P. Assessing the potentials of Bamboo and sheep wool fiber as sustainable construction materials: A review. *Mater. Today Proc.* **2021**, *47*, 4484–4489. [CrossRef]
19. Corscadden, K.W.; Biggs, J.N.; Stiles, D.K. Sheep's wool insulation: A sustainable alternative use for a renewable resource? *Resour. Conserv. Recycl.* **2014**, *86*, 9–15. [CrossRef]
20. Atbir, A.; Taibi, M.; Aouan, B.; Khabbazi, A.; Ansari, O.; Cherkaoui, M.; Cherradi, T. Physicochemical and thermomechanical performances study for Timahdite sheep wool fibers application in the building's insulation. *Sci. Rep.* **2023**, *13*, 503. [CrossRef]
21. Selvaggi, R.; Valenti, F. Assessment of fruit and vegetable residues suitable for renewable energy production: GIS-based model for developing new frontiers within the context of circular economy. *Appl. Syst. Innov.* **2021**, *4*, 10. [CrossRef]
22. Valenti, F.; Porto, S.M.C.; Dale, B.E.; Liao, W. Spatial analysis of feedstock supply and logistics to establish regional biogas power generation: A case study in the region of Sicily, Renew. Sustain. *Energy Rev.* **2018**, *97*, 50–63. [CrossRef]
23. Murray, A.T. Advances in location modeling: GIS linkages and contributions. *J. Geogr. Syst.* **2010**, *12*, 335–354. [CrossRef]
24. Comber, A.; Dickie, J.; Jarvis, C.; Phillips, M.; Tansey, K. Locating bioenergy facilities using a modified GIS-based location allocation-algorithm: Considering the spatial distribution of resource supply. *Appl. Energy* **2015**, *154*, 309–316. [CrossRef]
25. Laasasenaho, K.; Lensu, A.; Lauhanen, R.; Rintala, J. GIS-data related route optimization, hierarchical clustering, location optimization, and kernel density methods are useful for promoting distributed bioenergy plant planning in rural areas. *Sustain. Energy Technol. Assess.* **2019**, *32*, 47. [CrossRef]
26. Chen, W.; Zhang, S. GIS-based comparative study of Bayes network, Hoeffding tree and logistic model tree for landslide susceptibility modeling. *Catena* **2021**, *203*, 105344. [CrossRef]

27. 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]
28. Xie, C. Research on logistics facilities location based on GIS. In Proceedings of the 2nd International Conference on Data Science and Business Analytics (ICDSBA 2018), Changsha, China, 21–23 September 2018; pp. 358–361.
29. Ehmke, J.F.; Campbell, A.M.; Thomas, B.W. Optimizing for total costs in vehicle routing in urban areas. *Trans. Res. Part E-Log. Trans. Rev.* **2018**, *116*, 242–265. [CrossRef]
30. 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]
31. 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]
32. Parlato, M.C.M.; Valenti, F.; Porto, S.M.C. Covering plastic films in greenhouses system: A GIS-based model to improve post use sustainable management. *J. Environ. Manag.* **2020**, *263*, 110389. [CrossRef]