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Assessment of sheep wool waste as new resource for green building elements

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ABSTRACT

Within the context of circular economy framework and green deal statement, the valorization of greasy wool into new resources for insulation building components, represents an important challenge. The sustainable and innovative alternative uses of this livestock waste could create new opportunity for the growing of sheep farming sector and reduce environmental issues. By using Geographic Information Systems tools a tailored methodology has been carried out to evaluate the availability and geographical distribution of sheared sheep wool, with the aim of quantifying the correct scale required for a sustainable production of sheep wool insulation products. In detail, the hypothetical production of insualtion material based on wool waste, soft mats (100% wool) and semi-rigid panels (80% wool and 20% polyester), has been evalueted, at regional level and it was obtained that by reusing the computed sheep wool, i.e., 9,839,700 kg/year, more than 1,5 millions of soft mats or more than 11,5 millions of semi-rigid panels could be produced, which correspond, respectively, to more than 6.5 million and more than 17 thousand of square meter. These results, obtained by the conversion of raw wool into new resources, represent the first step for developing a new wool valorization chain.

1. Introduction

It is well known that building is the principal responsible of environmental degradation by intensely consuming non-renewable resources and causing land depletion and deterioration, solid waste generation, dust and gas emissions, and noise pollution [1]. In detail, worldwide, the 50% of carbon dioxide emissions, the 50% of solid waste production, and up to 50% of energy and natural resources consumption, are caused by the construction sector [2]. Therefore, an important goal for the building sector is to produce buildings with a minimum of environmental impact [3]. To mitigate the above-reported effects, i.e., CO_2 emissions, air, water, and soil pollution, and improve sustainability and energy efficiency of buildings, several efforts are made by researchers and technicians, that are focusing attention to new alternative construction materials [4,5]. Sustainability of buildings is achieved through the use of natural resources, energy conservation, by the valorization of renewable local materials, and in general, by a sustainable holistic approach starting at the stage of conceptual design and during all the life of the constructions, including the possible recycle of the building components [6,7]. Alternative construction materials are generally obtained by renewable sources, are recyclables, and with footprint impact lower than traditional building materials, e.g., concrete, steel, polymers [8]. Eco-friendly materials could be also deriving by the conversion of waste into new resources [9]. Furthermore, by considering the Green Deal and Circular Economy statements [10], the transformation of waste into resources for new production cycles is a priority for policy makers. The waste world production, including households, agriculture, commerce, industry, and construction origin, is estimated among 7 to 10 billion tons for each year [11]. This massive volume of waste if not properly managed and disposed of, determines air, water, and soil contamination, with severe consequences for world preservation [12]. Waste generation must be minimized, and as second opportunity, waste reuse and recycling into new suitable products should be increased [13]. Although efforts, the large part of waste is not properly managed and valorized, this is true mainly in developing countries [14]. The worldwide growth of agricultural production and the development of the intensive farming system also determined a significant increase of agricultural wastes (AW). Economic advantages could be obtained by the conversion of AW, by-products, and co-products into new resources; they are concerning the increase of the productivity of farming, the simultaneous reduction of production costs, the creation of new job opportunity, and above all the reduction in the

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disposal of by-products into the environment [15]. In order to offer alternatives to traditional materials based on the fossil resources as the Expanded Polystyrene (EPS) and, so, decarbonize the construction activities [16], several researchers dedicated their efforts on AW suitability and on their high potential as alternative materials for building applications [17–20]. The demand for sustainable building insulation materials has been increasing amongst the global concerns on sustainability and climate change mitigation. Particularly, renewable materials have become important [21]. Liuzzi et al. [22] studied thermal properties of a mixture composed of different percentages of clay, sand, straw, and cement to produce boards and bricks. The results showed that increasing the amount of straw ensured better thermal performances. Giroudon et al. investigated the effects of barley and lavender straw in unfired earth brick by varying fibres concentration (i.e., 3%, and 6% by mass). They found that by increasing the percentage of fibres, thermal conductivity decreases; the lowest values measured were of 0.28 W/mK for samples with 6% lavender straw and 0.15 W/mK for samples with 6% barley straw [23]. Asdrubali et al. [24] in their study collected information on bagasse/sugar cane used for thermal and acoustical insulating panels. Antunes et al. [25] evaluated panels consisting of rice husk, earth, gypsum, and aerial lime; also in this case the higher percentages of fiber improved insulating properties. Rojas et al. [26] evaluated the thermal performance of insulation materials consisting of wheat straw and corn peel fibers. In this context, the valorization of livestock wastes, such as sheep wool, as component of building elements, is gaining attention from researchers, technicians, and economic actors. This natural material has traditionally been used for production of textiles. The sheep wool insulation technology is quite advanced in terms of technology across many countries [27–29]. Thermal and acoustic insulating alternative materials, i.e., derived by sheep wool, are offered by green building market [16]. Sheep wool is at the same time a renewable resource, recyclable, and a sustainable building material with a low footprint. A sustainable growth is also based on valorising local construction material, as greasy wool, with the aim to reduce a huge amount of waste, by preserving the area where it is produced, i.e., rural areas and their landscape. An alternative use of wool waste as natural, renewable, and biodegradable building component represents an important advantage to reduce CO_2 emissions and environmental pollution. Despite its features, in several regions greasy wool it is not adequately disposed or recycled and is considered a solid waste that involves a problem of increasing concern for the complex and difficulty disposal management. A large amount of raw sheep wool, corresponding to 95%, is not suitable for the market, so the yearly sheep shearing activity is manly a cost for farmers, since wool is a special waste, that needs at least a sterilization treatment at 130 °C before its disposal [30].

In Europe in 2011, the estimated production of raw sheep wool based on sheep number was about 260,000 tons [31]. Moreover, the increasing waste landfill fees is often the main reason of the illegal disposal of raw sheep wool [32]. According to European Environmental Regulations (EC Regulation 1069 (2009), EU Regulation 142 (2011)), raw sheep wool must be sent to specialized sites for incineration or landfill, and only if it is previously washed or disinfected, it can be buried or burned without a permit.

Several studies focused on natural insulating fibres, and those related to the application of sheep wool fibres are becoming a new research topic [33–35].

Sheep wool fibre as insulating material has been far used in the construction field for its thermal and acoustic properties, and the possible conversion of this livestock waste for building application is the aim of numerous researches [36–38]. Wool in building sector is manly used as thermal and acoustical insulation material and as reinforcement fiber for bio composites to improve their mechanical behaviors, as ductility and shrinkage rate [39]. Other research works compared the thermal insulating capacity of sheep wool with rock wool [18,40]. In detail, Zach et al. [40] analyzed a thermal insulation made of sheep wool and found out that it showed similar characteristics to conventional mineral wool.

These studies, based on experimental measurements, showed that sheep wool is an excellent thermal insulation material very similar to mineral wool. Furthermore, by considering environmental aspects, sheep wool has many advantages as low transportation cost, because wool could be compressed with high reduction in volume, and highly energy efficient production. Sheep wool thanks to its chemical and physical performances, is suitable to improve indoor air quality (IAQ) and regulate the microclimatic conditions inside buildings [41]. Moreover, by using sheep wool insulation materials the well-being of building increases; wool by means of a chemical process said chemisorption neutralize some noxious elements, e.g., Toluene, Nitrogen Dioxide, Sulphur Dioxide, and Formaldehydes [42].

Several studies investigated the acoustic and thermal insulation property of sheep wool often by comparing its peculiarity with traditional insulation materials [40,43–45]. Results showed that wool is very performing, and in general comparable results were obtained for all kinds of investigated materials, e.g., polystyrene, glass wool, rockwool, with a substantial decrease of the embodied energy of sheep wool (the energy used for the production and transportation of a material). A previous study obtained results deriving by a physical and mechanical characterization of low-quality dairy sheep wool, totally unsuitable for textile industry, encouraged the use of this livestock waste as strengthen system for raw earth materials [39].

Sheep wool insulation components are already available on the market. Nowadays, by considering the Italian context, the products are 100% sheep wool soft mats (thicknesses from 10 mm to 120 mm), rigid or semi-rigid panels realized by sheep wool (70–80%) and polyester fibres (20–30%) (thickness from 50 mm to 120 mm); loose-fill fibres (Table 1). These products, i.e., semi rigid panel derived by concrete and SWF or adobe reinforced by SWF, are not present in the building market because they are still at an experimental stage. Moreover, both thermal and acoustic insulating component existing on Italian market are realized by wool imported from foreign nations, as Austria, Australia and New Zealand [46].

In this study, for the first-time, the aspects concerning the possible manufacturing process to convert raw wool, i.e., waste, into new building materials, i.e., resources, has been investigated. As the sustainability of sheep wool-made products depends on the availability and geographical location of sheared sheep wool, a tailored methodology has been implemented and analyzed, by using Geographic Information System – (GIS), with the aim of investigating the sheep wool possible reuse within a new wool valorization chain. Methods based on geographical information systems (GISs) have been worldwide used in other many disciplines as decision-making tools because they can solve location-allocation- related problems through, for example, minimizing transportation distances [47–50]. In this regard, GIS provides several tools for solving optimal logistic solutions and minimizing transportation costs therefore it was adopted to provide a model for developing the new wool valorization chain [51].

The conversion of raw wool into new resources for building applications represents a sustainable and innovative alternative to the waste of local low-quality wools by simultaneous reducing environmental pollution and creating new opportunity for the growth of sheep farming sector.

2. Materials and methods

2.1. Material

Sheep Wool is a natural Fiber (SWF) 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. Sheep wool considered in this work is unsuitable for textile industry and deriving by dairy sheep with a low-quality fleece.

Table 1
Based wool Insulation Building components existing on Italian market.

Type of product	Use	Picture of the product	Materials	Length [mm]	Width [mm]	Thickness [mm]	Density [kg/m^3]	U [W/m^{2}k]	λ [W/mK]
Roll soft mats	Thermal acoustical insulation	 *ISOLANA SYSTEMS srl*	100% sheep wool	6000	600	30 40 50 60 80	30	0.94	0.0318
Semi rigid panels	Thermal acoustical insulation	 THERMALAN ISO (Klimalan)	80% sheep wool 20% polyester fibers	1200	575	30 40 60 80 100 120	25	1.267 0.950 0.633 0.475 0.380 0.317	0.040

(*continued on next page*)

Table 1 (*continued*)

Type of product	Use	Picture of the product	Materials	Length [mm]	Width [mm]	Thickness [mm]	Density [kg/m^3]	U [W/m^{2}k]	λ [W/mK]
Loose-fill fibres	Thermal acoustical insulation		100% sheep wool	–	–	–	75–100	–	0.035

2.2. Study area

The research area considered in this work is Italy (Fig. 1); Italy is a European Nation shared in 20 regions consisting of a peninsula delimited at north by the Alps and surrounded by the Mediterranean Sea. In Italy, it is estimated an annual production of raw wool of 14,000 tons approximatively, of which the biggest part, around 95%, is totally unsuitable for the textile industry and without any commercial significance [43].

Every year all the sheep are shorn at least once, and the average wool produced is 1.5 kg per head for a total of more than 9000 tons of greasy wool. Moreover, nowadays in Italy exist only few examples of recovery of this special waste that is the initial phase for its possible reuse. Raw wool is already valorized only in three Italian regions, i.e., Sardinia, Tuscany, and Trentino Alto Adige.

2.3. Data analysis

In this paper, average data from 2017 to 2021 supplied by National Zootechnical Registry of the Italian Ministry of Health (IZS), were evaluated to implement a considerable database with the aim to quantify and localize both the sheep breeder farms, and the yearly sheep wool production, within the study area at regional level. A GIS - based model was put forward and applied in order to evaluate the regions, within the study area, where the production of sheared sheep wool is high. To simultaneous localize geographical data, to take into account, arrange, and examine data, GIS is the most suitable decision support tool [52–54]. With the aim to localize the territorial areas with the higher production of sheared wool a GIS-based model was implemented; obtained results were elaborated, evaluated, and analyzed with the final aim to supply basic information, suitable for developing a wool production chain in the selected study area. In detail, in this paper an open-source QGis software (ver. 3.10.11) was used.

Data from IZS were acquired and elaborated for analysing Italian regions by taking into account both the highest number of sheep farms and sheep number. Moreover, the related amount of yearly shared wool production, was carried out and identified on GIS software. All the GIS analyses were performed by using QGis software, by combining data supplied by the base maps (e.g., administrative boundaries from National Geoportal) and data coming from the database. Then, thematic maps and heatmaps were elaborated.

In detail, data from IZS related to the time interval 2017–2021 was elaborated for analysing the sheep sector trend. The phases followed to achieve the purpose of this study are below reported.

1. Data preparation for GIS-based analyses (December 2017–2021).
2. Spatial analyses for carrying out the GIS maps.
3. Evaluation and localization of the number of sheep and the related yearly wool production (SWF) at regional level (thematic maps).
4. Localization of sheep farms at regional level (thematic maps).
5. Quantification of the waste, by considering that the 5% of sheep wool is used for textile industry.
6. Quantification of soft mats and semi rigid panels production by adopting the 100% of waste, with tailored heatmaps production.

Specifically, by using the spatial analysis GIS tool data regarding farms and sheep number, were elaborated to evaluate the distribution of both farms and sheep at territorial level.

The next step was to develop a tailored methodology to evaluate the annual SWF production within the study area, at regional level.

By considering an average of 1.5 kg of wool produced for each sheep, a tailored index was computed with the aim to obtain the total amount of sheared wool in Italy.

The following equation was applied in GIS:

$$SWF = 1.5\ nS\ [kg] \tag{1}$$

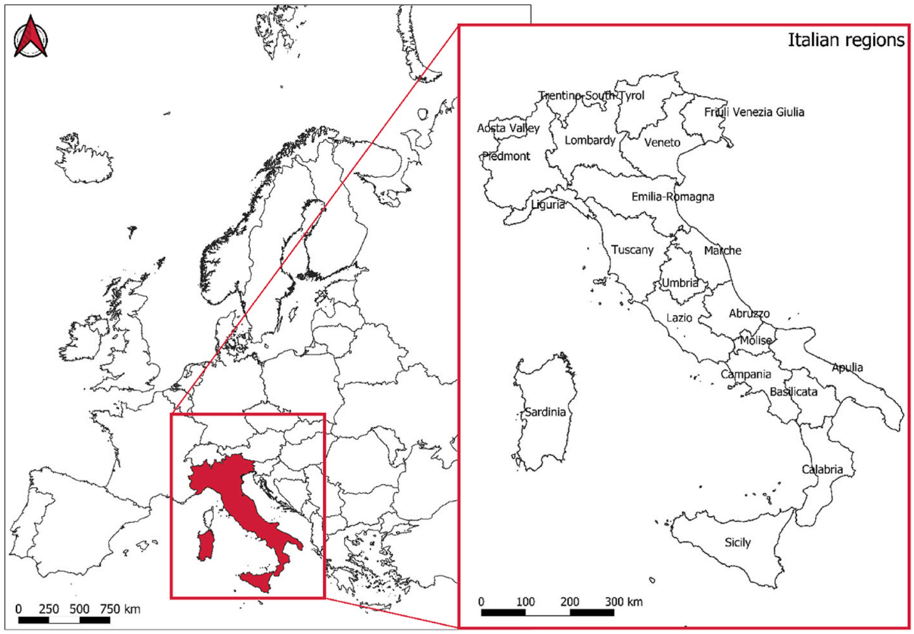

Fig. 1. Selected study area.

where:

SWF represents the total amount of sheep wool,

nS is corresponding to the number of sheep.

The amount of 1.5 kg of obtainable wool for sheep was adopted, as reported in literature [55,56] and verified by authors through an experimental trial performed in a sheep farm located in Sicily.

By the application of Jenks tool plug-in, available in QGIS software, the Italian regions were classified by obtaining a territorial distribution of the production areas, with the purpose of maximizing the differences among the classes. Then, to estimate territorial areas strongly characterized by both farms' number and wool production, all data were reported and analyzed.

Furthermore, since the 5% of produced wool is used by textile industry, consideration only regarding the 95% of waste were made.

Finally, by considering the 95% of sheep wool unsuitable for textile industry, the hypothetical number of both soft and semi rigid mats, obtained by the conversion of the computed wool waste into new green building components, were elaborated. Two different types of insulation materials were considered, 100% sheep wool soft mats (thicknesses 50 mm, dimension 6000 mm × 600 mm, density 30 kg/m^3), and semi-rigid panels, realized by sheep wool (80%) and polyester fibres (20%) (thickness 60 mm, dimension 1200 mm × 575 mm, density 25 kg/m^3). Then, to compute the surface covered by each insulation material the single surface covered area was computed equal to 3.6 m^2 for 100% soft mats and 0.69 m^2 for 80% semi-rigid panels.

3. Results

Data from IZS related to the time interval 2017–2021 were downloaded and elaborated for the Italian regions. As reported in Table 2 the

Table 2
Data acquired from IZS related to 2017–2021 time interval within Italy.

Regions	2017		2018		2019		2020		2021	
	Farms	Sheep	Farms	Sheep	Farms	Sheep	Farms	Sheep	Farms	Sheep
	[number]	[number]	[number]	[number]	[number]	[number]	[number]	[number]	[number]	[number]
Abbruzzo	6343	181,944	5897	179,419	5528	183,162	5474	169,747	5401	167,329
Basilicata	7362	194,527	7000	202,980	6034	202,975	5857	193,888	5685	181,723
Calabria	11,214	241,696	11,219	239,748	11,594	229,838	10,939	219,368	10,345	208,077
Campania	8439	180,015	8222	187,059	8206	187,060	8288	180,608	8143	178,091
Emilia Romagna	4272	46,545	4081	53,219	4024	55,110	4076	52,503	4133	52,373
Friuli Venezia Giulia	1519	18,488	1600	19,525	1661	20,323	1717	20,812	1734	16,524
Lazio	10,706	586,749	10,341	601,425	10,167	603,348	10,233	603,035	9919	594,885
Liguria	3180	6790	3217	7474	3070	8871	3108	8304	3111	9790
Lombardy	14,162	116,636	13,740	117,447	13,557	116,054	13,130	116,300	13,125	110,021
Marche	4342	128,809	4040	132,721	3988	131,315	3894	132,150	3783	122,545
Molise	2848	63,077	2745	62,148	2609	61,235	2495	58,905	2341	55,409
Piedmont	10,730	111,392	10,525	112,286	10,030	116,561	10,008	118,809	10,276	115,827
Apulia	4459	252,254	4305	243,609	4241	232,791	4173	215,414	4102	201,494
Sardinia	20,383	3,047,031	20,220	3,046,211	19,970	3,069,508	19,821	3,066,842	18,587	3,058,122
Sicily	11,579	834,900	11,759	827,442	11,863	819,491	11,231	782,818	11,076	751,727
Tuscany	6914	359,660	6803	351,944	6669	343,191	6533	337,723	6463	324,260
Trentino-South Tyrol	6908	72,921	7004	72,913	7315	75,260	7426	73,648	7653	73,123
Umbria	3632	96,180	3513	103,214	3409	104,822	3428	102,860	3383	97,527
Aosta Valley	667	2346	595	2420	692	2208	713	2168	756	1984
Veneto	5788	68,301	5824	70,577	5833	72,895	5667	69,259	5686	72,942
Italy	**145,447**	**6,610,261**	**142,650**	**6,633,781**	**140,460**	**6,636,018**	**138,211**	**6,525,161**	**135,702**	**6,393,773**

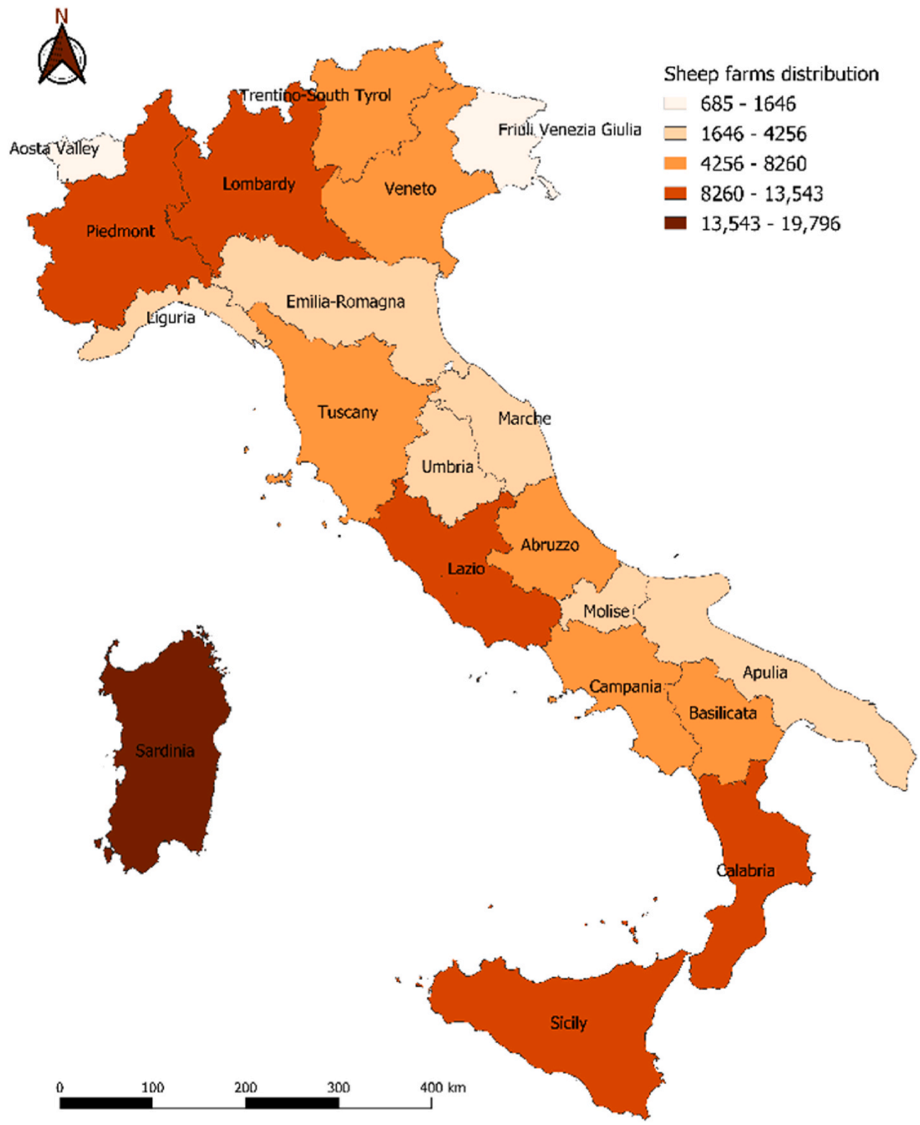

Fig. 2. Sheep farms distribution within Italian regions.

trend of the selected livestock sector was analyzed. In detail, as reported, a slight decrease in farms number was detected for all the regions, except for Trentino-South Tyrol, Friuli Venezia Giulia and Aosta Valley regions that registered an increase of about 10%. The highest decrease in farm number was detected for the region of Basilicata equal to about 23%.

By analysing data on sheep number, different results were observed. A slight increase in sheep number was recorded for Emilia Romagna, Liguria, Piedmont, Sardinia, Umbria, Lazio and Veneto regions. The highest increase about 44%, was recorded in Liguria region. The other regions registered a little decrease about an average of 10% per region (Table 2).

Furthermore, by considering the farms number the three regions with the highest concentration were found to be Sardinia, Lombardy, and Sicily over the time interval. Instead of, by considering sheep number, the three regions with the highest number of sheep were Sardinia and Sicily followed by Lazio region, over the considered time interval. In detail, more than 60% of sheep number is located between Sardinia and Sicily regions.

Data reported in Table 2 were averaged and elaborated in QGIS software in order to visualise the distribution of both sheep farms and sheep number at regional level. By adopting Jenks tool plug-in available in QGIS software the thematic maps reported in Fig. 2 was obtained. Italian regions were grouped in 5 intervals in order to maximise the differences among each class. Sardinia resulted the region with the highest concentration of sheep farms.

Then, by adopting Equation (1), based on the averaged sheep number computed per each region, by taking into account the compued index, the amount of SWF was computed and reported in GIS. A spatial analysis was carried out aimed at investigating the territorial distribution at regional level of the sheep wool waste, as reported in Fig. 3.

Results reported in Fig. 3 show as the regions of Sardinia, Sicily and Lazio had the highest concentration of sheep number.

Finally, by considering only the 95% of sheep wool, since the 5% is actually used for textile industry, the hypothetical number of both soft and semi rigid mats, obtained by the conversion of the computed wool waste into new green building components, were computed.

In detail, following the information reported in Table 1, by considering the 100% sheep wool soft mat, (0.18 m^3) 5.4 kg of sheep wool waste is needed for its production, instead of 0.828 kg of sheep wool is needed to produce one semi-rigid panel, (0.04 m^3) realized by sheep wool (80%) and polyester (20%).

Therefore, by taking into account the above reported values, for each Italian region the number of soft mat or alternatively the rigid or semi-rigid one was computed and reported in Table 3.

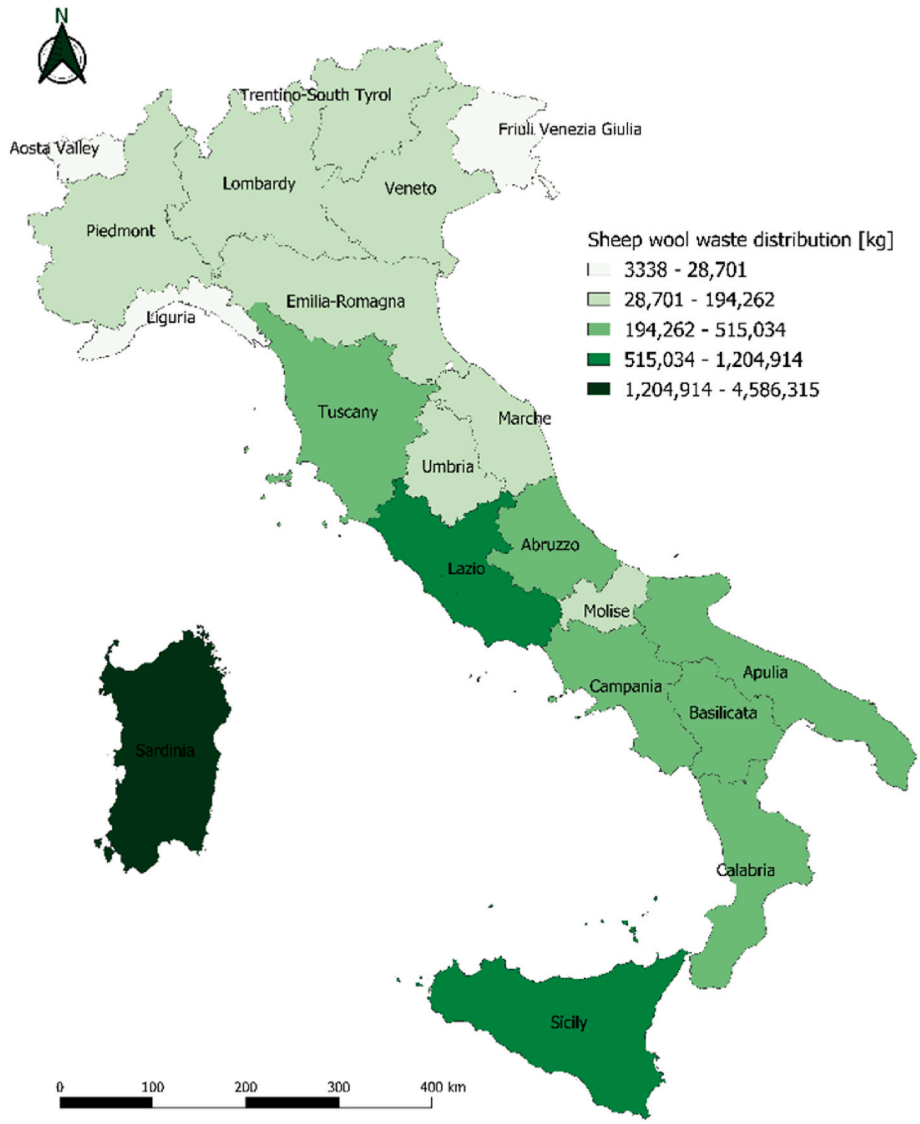

Fig. 3. Sheep wool waste distribution at territorial level within Italia regions.

By analysing results reported in Table 3, if all the produced sheep wool waste would be used for producing 100% wool waste soft mats, more than 1.5 million of mats could be produced. The regions of Sardinia, Sicily and Lazio could produce more than 65% of the Italian 100% wool waste mats. Instead of, by considering the production of 80% wool waste semi-rigid panels, the Italian regions that more contribute to produce panels per region are Sardinia and Sicily, with around 5.5 millions and 1.4 millions respectively; these two regions together could produce about the 60% of the total Italian 80% wool waste semi-rigid panels (i.e., around 11.8 millions).

Furthermore, by excluding the only three regions where there is already a wool valorization chain, i.e., Sardinia, Tuscany and Trentino-South Tyrol, the hypothetical production of soft mats could be more of 850 thousand and of semi-rigid panel more of 5.5 millions.

Then, in order to compute the surface covered by each considered insulation material, their single surface covered area was computed equal to 3.6 m^2 and 0.69 m^2 for 100% soft mats, and 80% semi-rigid panels, respectively. So, by taking into account this computed surface, and adopting data reported in Table 3, more than 6.5 million for 100% soft mats, and more than 17 thousand of square meter for 80% semi-rigid panels, could be covered.

4. Discussions

Sheep wool is a natural fiber obtained from the annual shearing of the animal's fur. The fiber unsuitable for textile usage could be employed for the realization of thermal and acoustical insulation building materials.

In Italy, only few regions reuse and valorize raw wool, i.e., Trentino South Tyrol, Tuscany, Sardinia.

The development of new wool chains widespread for all the national territory, could satisfy the Italian market requests, and a portion of the international one, of this natural insulation building component. As stated before in section 2.1, the based wool products existing on Italian market are prevalentely realized with wool imported from foreign countries, such as Australia, New Zealand, China, United Kingdom, South Africa and other places around Europe and Asia [57]. The use of local wool could also reduce the environmental impact of the whole supply chain by taking into account the logistic phase; by an economic point of view the reduction of transport due to the logistics and supply phase represent an important benefit in term of costs production, consequently the positive effects on the environment will be on reducing of pollution and CO_2 emissions.

In detail, after the annual shearing activity, the wool is generally

Table 3
Sustainable use, as new green building components, of sheep wool waste per region.

Regions	Sheep	Sheep wool waste	100% wool waste soft mats	80% wool waste semi-rigid panel
	[number]	[kg]	[number]	[number]
Abbruzzo	176,320	264,480.00	48,978	319,420
Basilicata	195,219	292,828.50	54,228	353,658
Calabria	227,745	341,617.50	63,263	412,582
Campania	182,567	273,850.50	50,713	330,737
Emilia Romagna	51,950	77,925.00	14,431	94,112
Friuli Venezia Giulia	19,134	28,701.00	5315	34,663
Lazio	597,888	896,832.00	166,080	1,083,130
Liguria	8246	12,369.00	2291	14,938
Lombardy	115,292	172,938.00	32,026	208,862
Marche	129,508	194,262.00	35,974	234,616
Molise	60,155	90,232.50	16,710	108,976
Piedmont	114,975	172,462.50	31,938	208,288
Apulia	229,112	343,668.00	63,642	415,058
Sardinia	3,057,543	4,586,314.50	849,318	5,539,027
Sicily	803,276	1,204,914.00	223,132	1,455,210
Tuscany	343,356	515,034.00	95,377	622,022
Trentino-South Tyrol	73,573	110,359.50	20,437	133,284
Umbria	100,921	151,381.50	28,034	182,828
Aosta Valley	2225	3337.50	618	4031
Veneto	70,795	106,192.50	19,665	128,252
Italy	**6,559,800**	**9,839,700**	**1,822,167**	**11,883,696**

*All reported values based on the values averaged on time interval 2017–2021.

washed with natural soap and sodium carbonate in order to remove grease and any impurities. Subsequently, depending on the type of final product to be obtained, wool is processed in different ways, e.g., carded, and pressed treatments. In any case the process required for reusing wool in building sector are less impactful than the treatments needed to obtain a wool suitable for textile applications.

Within texile industry, the foreseen wool chain is complex and long, it starts on farm by the yearly production of raw wool, and go through different processing phases, i.e., storage phase, transport, scouring and combing, spinning, dyeing, weaving, finishing, cutting and sewing, with important impact on water and energy consumption, greenhouse gas emissions (GHG), and pollution increment due to the chemical additive used during these different phases [58]. With regard raw wool for building applications, the production phases are reduced to storage, transport, washing by natural soap, rinsed, dipped in a borax solution for pest control, and rinsed again, by minimizing processed product and embodied energy since fleece is a natural by-product.

By an economic point of view, and by considering the formula that Drucker et al. (2001) proposed to quantify the value of a livestock product [59]:

$$TEV = DUV + IUV + OV + NUV$$

Where: *TEV* = Total Economic Value; *DUV* = Direct Use Value (meat, wool, milk, work etc.); *IUV* = Indirect Use Value; *OV* = Option Value; *NUV* = Non-Use Value

The results achieved in this study and the holistic considerations could provide useful information to reduce the *NUV* factor, by at the same time increase *DUV*, and *TEV* consequently.

In detail, *NUV* factor decreases by increasing the use and consequently the economic value and the benefits for farmers that could consider wool no longer as a problem to solve but as a resource to valorize.

5. Conclusion

In this paper for the first time real analyses and discussions related to the hypothetical building insulation production of wool soft mats and semi rigid panel by the conversion of sheep wool waste, have been done. In detail, by elaborating data from 2017 to 2021 acquired by IZS of the Italian Ministry of Health, a GIS - based model was put forward and applied in order to evaluate the territorial areas, within Italy, with the highest production of sheared sheep wool.

Then, based on acquired and analyzed data, the hypothetical production of insualtion material based on wool waste, soft mats (100% wool) and semi-rigid panels (80% wool and 20% polyester), has been evalueted, at regional level. By the reuse of the produced raw sheep wool waste, i.e., 9,839,700 kg/year, more than 1,5 millions of soft mats or more than 11,5 millions of semi-rigid panels could be produced, which correspond, respectively, to more than 6.5 million and more than 17 thousand of square meter.

The valorization of greasy wool could satisfy the request of Italian building sector and, since nowadays the wool Italian products are mainly realized by imported wool from Australia, New Zealand, China, United Kingdom, South Africa and other places around Europe and Asia, it could contribute at reducing the environmental impact due to the logistics and supply phases.

CRediT authorship contribution statement

Monica C.M. Parlato: Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation. **Simona M.C. Porto:** Visualization. **Francesca Valenti:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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